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Quarterly Technical Summary

General Research

15 May 1967

Prepared under Electronic Systems Division Contract AF-119(628)-5167 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts



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Quarterly Technical Summary

General Research

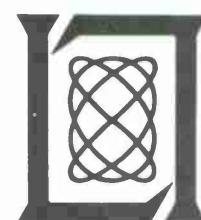
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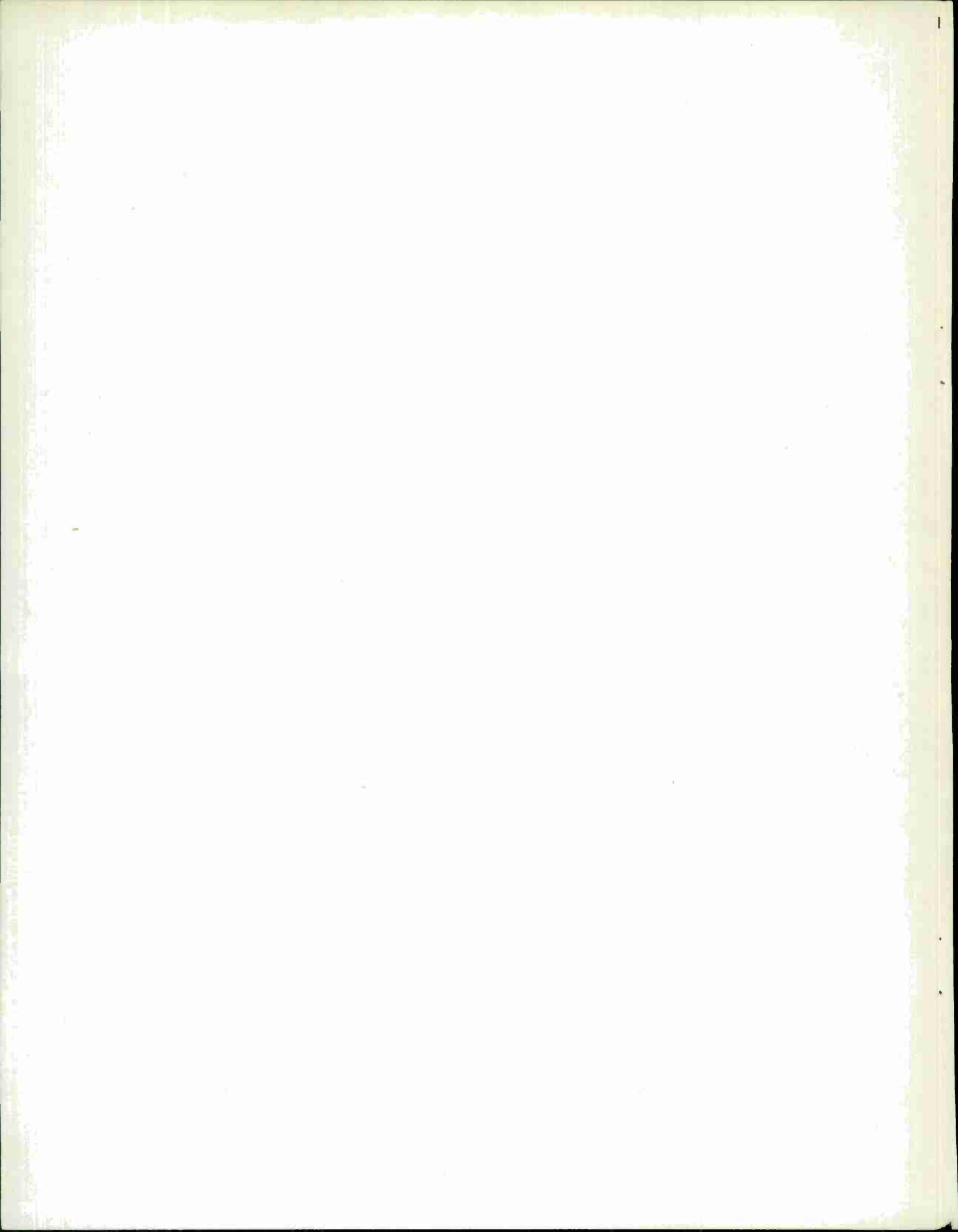
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Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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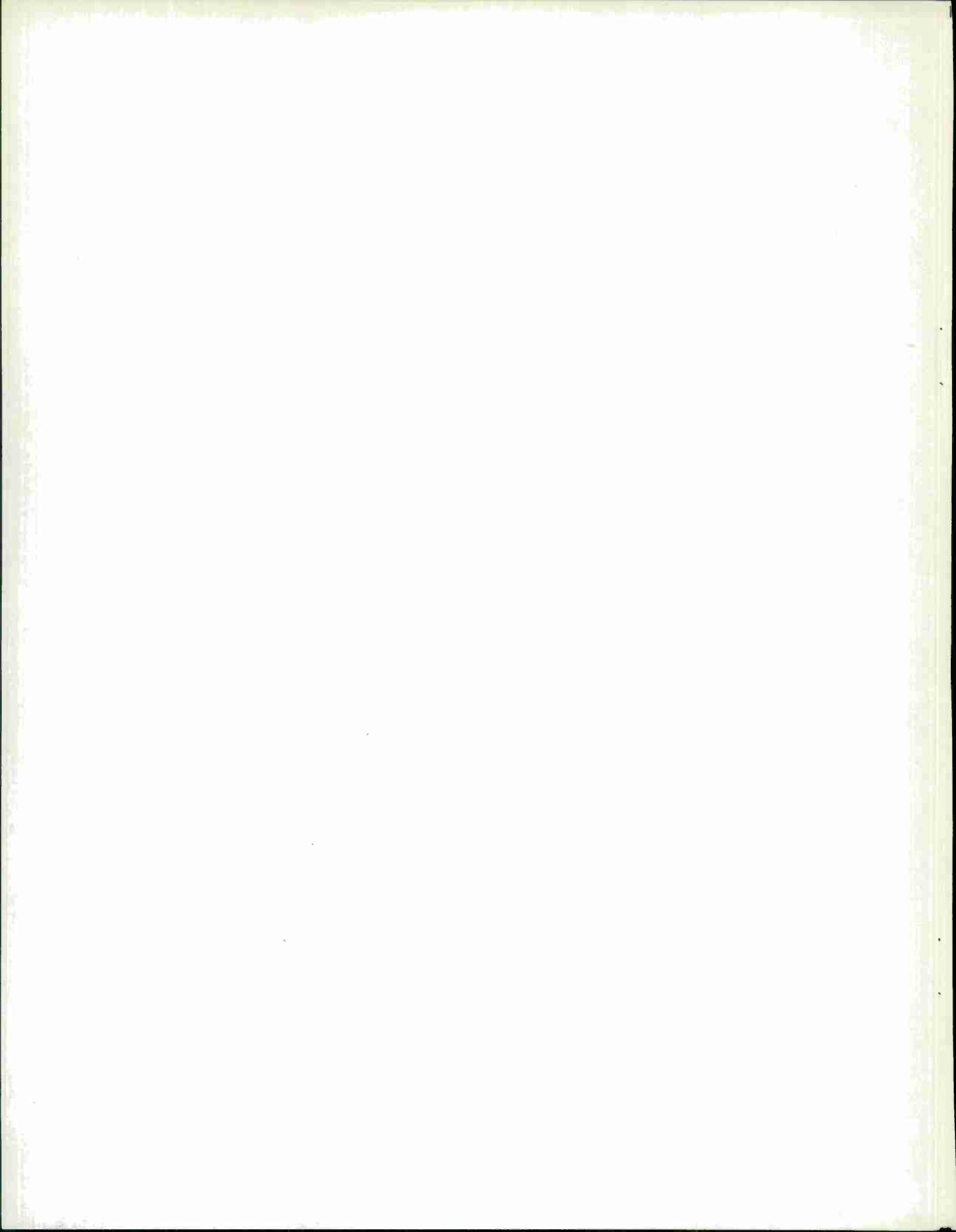




INTRODUCTION

This Quarterly Technical Summary covers the period from 1 February through 30 April 1967. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office



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DATA SYSTEMS DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 February through 30 April 1967 for the General Research Program of Division 2. Separate progress reports on Ballistic Missile Re-entry Systems, Graphics, and Project PRESS describe other work in the Division. All the work of Groups 21 and 22 and some of the work of Groups 23, 25, and 28 is therefore reported separately.

F. C. Frick
Head, Division 2

V. A. Nedzel
Associate Head

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1967

PUBLISHED REPORTS

Journal Article*

JA No.

2763	Oblique-Incidence Magnetic Anisotropy in Codeposited Alloy Films	M. S. Cohen	J. Appl. Phys. <u>38</u> , 860 (1967)
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UNPUBLISHED REPORTS

Journal Articles

JA No.

2986	Content-Addressed Memory Using Magneto-Optical Interrogation	D. O. Smith K. J. Harte	Accepted by IEEE Trans. Electron. Computers
3047	Magnetic Films and Optics in Computer Memories	D. O. Smith	Accepted by IEEE Trans. Magnetics

Meeting Speeches†

MS No.

1884	Wave Optical Aspects of Lorentz Microscopy	M. S. Cohen	Seminar, Purdue University, 7 March 1967
1884A	High Resolution Lorentz Microscopy	M. S. Cohen	Colloquium, General Telephone and Electronics Laboratories, Bayside, New York, 20 April 1967
1920	Conic Display Generator Using Multiplying Digital-Analog Decoders	H. Blatt	Fall Joint Computer Conference, Anaheim, California, 14 - 16 November 1966
1944	Magnetic Films and Optics in Computer Memories	D. O. Smith	Intermag Conference, Washington, D.C., 5 - 7 April 1967
1974	Some Observations on Time-Sharing Based on Experiences with APEX, the TX-2 Time-Sharing System	J. W. Forgie	Association for Computing Machinery, Waltham, Massachusetts, 20 April 1967

* Reprints available.

† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

DIGITAL COMPUTERS GROUP 23

I. COMPUTER SYSTEMS

A. TX-2 Optical Scanner

A general-purpose two-channel analog output device, for time-shared use, has been built and is ready for checkout. It will be used in future image dissector work and by those projects requiring program-controlled analog voltages at a user's console.

Deflection tests on the camera equipment showed great improvement in linearity as a result of replacing the deflection amplifiers. For the first time, meaningful focus coil current data were taken; dynamic focus correction circuitry will be designed after further tests.

B. Input/Output Processor Module

Design work has been completed and the hardware is in construction for adding the long-word large-capacity film memory to TX-2. The prospect of additional main memory which also has a cycle time of under 1 μ sec has led to a re-examination of the minimum frame cycle time for TX-2. It now appears feasible to reduce this time to 1.2 μ sec, and to operate new processor modules on the memory bus switch at 0.8 μ sec. The new input/output processor module which is now being designed will use this as its limiting frame cycle time.

C. TX-2 Computer Network Synchronous Data Terminal

A Data Terminal unit is being designed and constructed which will connect a Western Electric 201A data set to the Low-Speed Data Channel. This will provide a 2000-bit-per-second, full-duplex, synchronous, 8-bit-per-character, communication link for the TX-2. This link will connect either to the DEC 338 Programmed Display at ARPA in Washington, D.C., or to other similarly equipped data terminals. Completely independent transmitter and receiver data assembly logic is provided. Idle and synchronizing characters are under program control.

II. MAGNETIC FILM ENGINEERING

A. Large Capacity Memory (LCM)

Exerciser:— Mechanical and electrical design of the memory for use in TX-2 has been completed. An exerciser is being built to test operation of the complete 1 million-bit memory off-line. Memory capacity will be 25,600 forty-one-bit words. Each byte (9 bits) will have a parity bit, and all eight sub-words in a memory long-word will be parity checked on each read cycle.

Film Preparation:— Two new approaches have been successful in producing magnetic films for LCM. The properties required are 1200- \AA films with $H_c \geq 15$ Oe, $H_k \leq 15$ Oe, and $\alpha_q \leq 4^\circ$. Difficulty in repeatably obtaining sufficiently high H_c without exceeding the α_q angular dispersion limit was experienced using the copper diffusion technique. In place of diffusion, a

Division 2

Co-Ni-Fe-Cr alloy or a double-layer Co-Ni-Fe and Ni-Fe film has been shown to have the desired characteristics.

LCM Digit Circuits:- Circuit boards for 100 four-channel digit cards have been received from the vendor; component assembly is in progress.

LCM Connections and Lines:- A full set of digit patterns for LCM has been produced. Manufacturing problems due to imperfections in the material, exposure errors, and dust have required multiple inspections throughout the process. Finished lines have excellent definition.

Word-line production has evolved into a routine process. However, the pressure connection between diode arrays and word lines is being re-evaluated. The plated button contacts currently in use appear to have a limited lifetime when subjected to many insertions. A connector using spring-loaded pins as contacts has been built and is being evaluated as a possible replacement.

B. Pattern Scribing

Tests of newly sharpened diamond scribing tools have confirmed findings made on the production scribing machine that good scribing cannot be accomplished with these tools. Some minimum amount of dulling of the tools must occur before they will scribe well. The "dulling" consists of grinding a 0.0002-inch-wide flat on the bottom of the tool.

C. Precision Etching

Visual inspection of etched digit-line patterns is made difficult by the presence of edge roughness at the interface of the copper cladding and the glass-epoxy base material. The roughness is due to copper which is embedded in the base material during the laminating process and which is slow to etch away. At present, the most promising method of improving the line-edge definition is to employ a short-duration, high-velocity spray etch.

D. Contamination Control

A temporary "clean tunnel" has been used successfully for assembly of the LCM stack. Work is performed within a sheet plastic tunnel, the end of which is supplied with air filtered to a level of 0.3μ . The clean air, combined with the use of "clean room" frocks, hats, and gloves for personnel working in the tunnel, has eliminated dust, lint, and fibers which were causing difficulties with memory operation.

E. Extended LCM Stack

Memory superstructure parts for this stack have been completed. This configuration, which will accommodate 26 substrates, requires digit lines twice the present length. Experiments in splicing together digit pieces to achieve the required length are in progress. One splicing method being evaluated is RF induction heating of solder-plated line segments for simultaneous soldering of all lines at a joint; infrared heating is also being investigated.

F. Ground Plane Experiments

Four techniques for successfully applying an insulating layer on memory ground plane substrates are being evaluated:

- (1) Dipping substrates in high-temperature plastic and baking.
- (2) Sputtering glass on the ground plane.
- (3) Reactive chemical deposition of SiO₂ (quartz).
- (4) Evaporating C₈F₂ (calcium fluoride) in hard vacuum.

G. Fine-Line Scribing

The smaller version of our automatic scribing device is now fully operational. It provides an experimental capability for fine-line scribing studies.

H. Magneto-Optic Film Tester

A prototype of a new film tester has been built and is capable of displaying the B-H characteristics of local regions ($\frac{1}{8}$ -inch diameter) of a magnetic film by means of the Kerr magneto-optic effect. Production drawings are being prepared for the field coils and film-positioning table of the final version.

III. SYSTEM PROGRAMMING AND APPLICATIONS

A. Display Executive

The first version of the interrupt executive has been completed and placed in service. Test programs for the new conic scope hardware have been run satisfactorily; completion of this display system is awaiting installation of a character generator and control logic. When this equipment is installed, extensive changes to the display executive will be required.

B. Mk 5

Recent work on Mk 5 has concentrated on the design and implementation of debugging techniques. Methods for high-speed monitoring of program flow have been designed and almost completely implemented. FLOW-MAP and TRACE are thereby accelerated tremendously. Work has begun on a symbolic disassembly facility which would take run-time contents of machine and program registers and "disassemble" them back into any of a number of forms of source language. In order to aid in the debugging of Mk 5 itself, Mk 5 prints information about its own errors on the main Lincoln Writer console when it detects them.

C. Languages

The phase-one VITAL system has remained relatively stable during this past quarter. Development of compilers using this system has continued. A language for associative processing has been almost completed and checked out. The table-driven recognizer features of VITAL have been incorporated into a general-purpose "Front End." When completed, this program is intended to serve many uses in interactive console programming. One builds an input program for some interactive console language by describing the language in productions which can then be translated directly into the recognizer tables.

D. Network

Programming of the 338 remote display console has continued during the past quarter. A slippage in the completion of the TX-2 hardware interface has prevented tests of the two computers

Division 2

jointly. The programs are ready, and completion of the hardware is expected during the next quarter.

The network link between the TX-2 and the AN/FSQ-32 at SDC has been used for several demonstrations. A distributed program which uses the Lincoln Reckoner at TX-2 and LISP at SDC has been created and run. Statements typed in at TX-2 are parsed at SDC and then given to the TX-2 Reckoner for calculation. Some statistics on network operation are being gathered.

IV. TRANSISTOR AND CIRCUIT DEVELOPMENT

A. Microsystems

A test set for evaluating the 27-bit parity circuit has been constructed. This parity micro-circuit array contains 520 transistors and 234 resistors. The problem of making 2^{27} individual checks, and its attendant mass of logic circuitry, is circumvented by testing individually each of the thirteen 3-bit parity cells which make up the array. This is accomplished by using a programmable rotary drum switch to select its required inputs and bias off the remainder. The test procedure then becomes the relatively simple task of making eight checks on each of the thirteen 3-bits.

B. Machine-Aided Design

Circuit evaluation studies are now being performed with the CIRCUS program on the IBM 360 computer. We have developed a plotting routine which gives computer-generated output curves in addition to the standard printed data. To date, several satisfactory analyses of the transient performance of the 3-input current-mode SMX-4 gate have been performed. The circuit used has all the parasitic diodes and capacitances included. Rise times are about 1.25 nsec, which is longer than expected. Further analysis will be directed toward the determination of critical parameters.

An attempt to run a 5-stage chain, which could be compared with experimental data, proved to exceed the capability of the program. This was reduced to 3 stages and resubmitted. Results are not yet available.

C. Associative Memory Array

The basic cell for the 4×4 associative memory array has been designed and now includes the necessary drivers. The total array will contain 404 resistors and 352 transistors within a 60 \times 60 mil area. Because the drivers are used only around the periphery, there will be 60 unused resistors and 48 unused transistors within the array. The mask set for the individual cell has been drawn, and the masks for the two upper layers are being completed.

COMPUTER COMPONENTS GROUP 24

I. MAGNETIC FILMS

A. Anisotropy Spectrum of Magnetic Films

Rotating magnetic annealing studies of nonmagnetostriuctive permalloy films have been extended to 250°C. It is found that the peaks present at lower temperatures disappear, leaving only a broad background indicating a distribution of activation energies. There are also indications of a new peak appearing at the low-frequency end of the spectrum (relaxation time $> 2 \times 10^3$ sec.).

Some difficulty has been encountered with changing background DC magnetic fields of the order of 5 mOe. A major source of this interference was found to be automobiles parking alongside the laboratory, and a parking ban has been instituted to eliminate this effect. Other sources of interference could not be identified, but will be compensated for during slow anneals by an oppositely directed measurement-pair method that uses the film as a sensitive gaussmeter.

B. Wave Optics of Lorentz Microscopy

The theoretical analysis of the wave optics of Lorentz microscopy referred to in the previous Quarterly Technical Summary* has been completed and is now in press.[†] This analysis shows that the most practical methods for studying domain wall and ripple structures involve use of the defocus method. To realize these methods experimentally, an electron beam having high coherence must be achieved. Attempts to achieve the required coherence with our RCA EMU3 microscope have not yet succeeded, primarily because of electrical and mechanical stability problems. To date, only four interference fringes have been seen, while at least ten are required.

II. OPTICS

A. Magneto-Optical Interrogation with Phase Modulated Light

A modulator is being assembled which uses a moving mirror in the form of a quartz crystal oscillating in a longitudinal mode to generate phase modulation of one component of linearly polarized light. Mixing with the orthogonal component occurs in an interferometer arrangement, resulting in output light having the form of a time-varying Lissajous pattern.[‡]

* General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 February 1967), p. 9, DDC 650401.

† M. S. Cohen, "Wave Optical Aspects of Lorentz Microscopy," Technical Note 1967-21, Lincoln Laboratory, M.I.T. (10 May 1964).

‡ D. O. Smith, "Magnetic Films and Optics in Random Access Computer Memories," presented at Intermag Conference, Washington, D.C., 5 - 7 April 1967.

Division 2

B. Thermal Writing

The thermal cycle time has been calculated for a magnetic film bit written by means of a focused electron or photon beam.* The heat-flow model approximates the memory bit as a planar disk source, and the cycle time T is determined by the condition that, for repetitive writing, the ratio of transient to DC temperature must be >1 . Then it is found that the bit radius a must be $\ll \sqrt{\kappa T}$ = thermal diffusion length in time T (κ = thermal diffusivity of substrate). For $T = 1 \mu\text{sec}$ and an Ag substrate, this gives $a \sim 5 \mu$.

C. Magneto-Optical Memory Read-Out Using Thermal Modulation

A number of workers have considered using an electron beam (EB) or photon beam (PB) for writing and reading bits in a magnetic film memory. These studies have encountered the following two problems which limit the usefulness of beam techniques applied to memory problems, namely: (1) sufficiently wideband, high-resolution light deflection is not currently available for memory addressing, and (2) the interaction of electrons with ferromagnetic spins is too weak to provide a practical means of EB read-out. These problems can be overcome by simultaneously using an EB and a PB. Briefly, the EB is used to thermally write into a memory bit, which can be done at high speed and resolution. Reading is accomplished by the combined use of an EB and a PB in which a magneto-optical signal is thermally modulated by an intensity-modulated EB. The upper frequency limit of thermal modulation is again given by $a = \sqrt{\kappa T}$ so that for $a = 1 \mu$, $f = 100 \text{ MHz}$, which implies read-out times $< 1 \mu\text{sec}$.

III. ELECTRON TRANSPORT

A. Variation of α with Collector Voltage in a Metal-Insulator Triode

The value of the saturated α of a metal-insulator triode is found experimentally to be a strong function of the collector-to-base voltage V_{eb} . Experimental measurements of α vs V_{eb} indicate that α increases exponentially with V_{eb} . Varying the collector insulating-oxide thickness reveals that α decreases with increasing oxide thickness for any given value of V_{eb} . This suggests that α is actually an exponential function of the electric field in the collector oxide rather than V_{eb} . However, more precise measurements of the collector oxide thickness will be necessary before the field dependence of α can be verified. No satisfactory theory of these effects has yet been found.

B. Variational Method in Transport Theory

Recently, we reported a new variational approach in the transport theory of the coupled electron-phonon system. For the problem of electrical conductivity, we have been able to

* D. O. Smith, "Magnetic Films and Optics in Random Access Computer Memories," presented at Intermag Conference, Washington, D. C., 5 - 7 April 1967.

obtain an exact variational principle for the long-wavelength response, within the well-known "ladder" approximation to the Bethe-Salpeter equation. In obtaining this variational theorem, considerable use is made of the generalized Ward identity for charge conservation.

We are presently considering whether the same techniques can be applied to the calculation of other transport coefficients, such as the thermal conductivity. Here, the analogy to charge conservation is, of course, energy conservation. We have been able to show that there exists a certain generalized Ward identity for the 4-vector energy current vertex functions, and to find an approximation in which this identity is satisfied. We are attempting to utilize these results to obtain a useful variational principle for the thermal conductivity.

PSYCHOLOGY GROUP 25

I. USE OF TX-2 FOR MAN-MACHINE INTERACTION

A. APEX

The basic routines which govern the sharing of time and memory in the APEX time-sharing system have been substantially modified during the past quarter in order to change the scheduling strategy of the system. It had been assumed that the supply of core memory would generally be adequate to contain all the active programs, so the strategy was to cycle rapidly through the active programs to achieve rapid response. With the increased requirements of current users, the supply of core memory is more often inadequate, and the old strategy was no longer appropriate; rapid response was not achieved, and computational efficiency was poor in many cases. The new strategy is better suited to the current mix of users. It gives greater overall computational efficiency and shows a dramatic improvement in certain types of applications against which the old strategy discriminated.

However, the system does cycle more slowly under heavy loads and, in that case, does not respond rapidly enough for some kinds of interactive graphics. In order to achieve fast response in the presence of heavy loads, a new scheduling scheme is being designed with which a task can be split into two parts and a different scheduling strategy applied to each. One part can be small and scheduled to run in frequent short bursts to maintain interaction with the human user; the other part can be large and scheduled to run in less frequent, but longer intervals to achieve computational efficiency.

The monitor routines needed for digital-to-analog output during time-sharing are now operating. Work on magnetic-tape routines is again being postponed until the new tape units are operating with programs outside the time-sharing system.

B. Coherent Programming

Coherent programming is a type of standardization that makes it easy for one programmer to build on the work of another, and for the user to switch back and forth between packages of services provided by different programmers.

One aspect of coherence is in operands and results: this means that each program files with its results enough descriptive information so that a new program, if asked to operate on those results, can determine how it should behave — i.e., whether the results are of a type on which it can operate and, if so, how they should be processed.

During the past quarter, coherence in operands and results has been considerably improved by the introduction of data-types. The community of TX-2 programmers has now standardized three types of files: a file of text in standard format, a process (i.e., a string of system commands that the Process Runner will run off automatically), and an n-dimensional array of single-precision floating-point numbers. Data-type codes have been established for these three types of files, and the programs that create these files now deposit the appropriate code in the system

directory when the file is created. The programs that pass a file from one user to another, or permit a user to copy one of his own files, have also been modified to pass along the data-type.

With the establishment of data-types, it has been possible to begin a policy of making the public service programs more general. In displaying a file of data – and in other cases where a user's error would not have disastrous consequences – the user should not have to call on different programs to operate on files of different types; he should be able to call on one program that inspects the data-type and behaves accordingly. The service programs that display files on the typewriter, Xerox, and CRT have therefore been modified so that they will display files of the three standard types, first inspecting the type code to see how the display should be composed, and the text-editor has been generalized to edit processes. Introduction of a standard format for text has had other consequences also. Source programs for the Junior compiler can be written as text files, edited if necessary, and compiled by a routine that does little more than construct a text file of meta-commands to the compiler-compiler.

The other aspect of coherence is in calling: this means that programs call each other in a standard manner that allows the user of a problem-oriented language to call for calculations described in another language – all without any explicit cooperation between the designers of the two languages. The difficulty in achieving this sort of coherence arises in passing parameters through one language into another whose syntax may not be known to the designer of the first language.

A standard set of calling conventions that sufficed for a restricted range of languages has been used in many TX-2 programs for some time. A more flexible set of conventions that suffice for a much wider range of languages has now been agreed on, and the task of assisting programmers with the fairly simple task of converting to the new standard has been undertaken. Fortunately, a way has been contrived to keep both the converted and the unconverted programs working during the transition period.

C. Lincoln Reckoner

The Reckoner is a coherent set of programs in the public library of the APEX time-sharing system. It is designed for exploratory analysis of data and theoretical problems.

An algebraic translator for element-by-element operations on n-dimensional arrays of numbers has now been added to the library. The character of this program, whose public library name is 5ELE, is best seen from an example of a statement that asks for its use:

5ELE {JOE²×(JIM+BILL)/2.5→SAM

Assume that BILL is a constant and that JOE and JIM are 6×17 arrays. The translator creates and executes a small loop of instructions that index through the arrays JOE and JIM, performing the indicated operations on corresponding elements of those arrays. The operations are performed by jumps to built-in subroutines, and the results are deposited in a new 6×17 array called SAM. The common mathematical functions are available – logarithm, arc tangent, absolute value, etc.

The statement illustrated above could appear in a process in which JOE and JIM were variable parameters. This flexibility is possible because of the new calling conventions mentioned in Sec. B above.

Division 2

In addition, two small routines have been added to the library, and improvements have been made to the routines for deleting or saving rows or columns of two-dimensional arrays. The rows or columns to be operated upon can be specified by naming a vector that contains the row or column numbers. The change also permits, in the case of saving, the rearrangement of rows or columns.

II. USE OF IBM 360/67 FOR MAN-MACHINE INTERACTION

A. General System Editor

The General System Editor will be a software service operating in the general framework of TSS/360 and other operating systems on the Model 67 computer. Its principal functions will be (1) to provide facilities for editing data, text, and programs, (2) to provide these facilities for on-line users, and (3) to enable other software systems to use these facilities directly. A contractor has completed the design for the basic Character Stream Editor, and coding for many of its modules is in various stages of completion.

The Character Stream Editor provides a corpus of "Kernel Functions," each of which does some particular manipulation. It is expected that most users will not use the Character Stream Editor directly, except, for example, as a last resort to override restrictions on format or syntax. Other Editors will make large use of the Kernel Functions and, in addition, may have some special functions of their own.

The Text Editor will initially be a keyboard editor (i.e., will not include CRT displays of the text). It will be an extension of the TYPSET commands from Project MAC and of related systems such as QED and TECO. The Fortran Editor will facilitate the preparation of programs in Fortran IV; its purpose is to produce a data set that is acceptable to the Fortran language processor. It will include a fair level of language analysis. For example, it will recognize and possibly correct errors in labels, arguments, syntax, and naming conventions. Functional specifications for these two editors are expected to be completed by the middle of the summer.

The Editor System will not operate directly on the actual strings of characters. Instead, it will operate on tables that are constructed as needed from the material being edited. It will use linked list structures that seem to promise reasonably efficient operation under paging.

B. Documentation and On-Line Education

Work continues on a documentation and educational package for new users of the time-sharing system. In addition to consultants (available on-line, over the telephone, and by actual visit), a new user needs:

- (1) A set of manuals on the system and its subsystems. Work has begun on two of them: one for the almost absolutely naive user at a typewriter terminal - Model 2741; the other for the moderately skilled Fortran programmer without time-sharing experience. These manuals will give examples of actual use.
- (2) A set of monitoring programs to help guide users of the manuals. These programs will inform the on-line user about his errors, about machine and system requirements, about how to find further information, etc. An example is the proposed EXPLAIN command, which would interactively and with examples explain the meaning and use of a large number of terms that occur in the manuals and on the system, including all the error messages.

Partial drafts of these two manuals have been prepared, and the text of the responses that the monitoring programs will make in various situations is being written. The introduction of this text into the time-sharing system will be greatly aided by the Editor discussed in Sec. A above, as will the editing and updating of the manuals themselves.

C. Facility Similar to the TX-2 Reckoner

The design of a Reckoner Facility for the Laboratory IBM 360/67 time-sharing computer has been completed. It will be a facility for on-line numerical analysis, similar to the current Reckoner on the TX-2 computer. The main purpose in transferring the facility to the Laboratory computer is to make it available to any staff scientist or engineer near his work area and at times of his own choosing.

The design is based on a "Mediator," a general service for running programs on-line. The Mediator provides automatized directory services, program control, and file management so that the user may express his orders to the machine in simple statements containing only the minimum essential information. The scientist or engineer uses a computer to improve his knowledge by running programs. It is contended that if his thinking is burdened by attention to endless trivial detail in this endeavor, he will be handicapped in arriving at insights into his real problems. By making use of Mediator services, programmers can free the user from most of the irrelevant clerical tasks.

With the addition of a few statements, any Fortran computational subroutine can be adapted to run under the Mediator in the current design. Thus, a collection of programs that perform array arithmetic, matrix algebra, and in-out functions are to be written in Fortran to run under the Mediator. These, along with a Builder and Runner to pre-define and execute strings of commands, will constitute a Reckoner. Other collections of program modules — e.g., to retrieve data or to simulate a system — can also readily be adapted to run under the Mediator. Because the Mediator is based on the principles of coherent programming, a module from one collection of routines is automatically ready to be used in conjunction with another. Thus, the new Reckoner, like the old one, is a collection of routines that alone constitute a facility for on-line analysis of data and mathematical models. In conjunction with other routines, general or specific in their application, it provides a core facility for system simulation, analysis of samples of large data bases, etc. Thus, it is particularly responsive to the needs of scientists and engineers at a large research institution such as Lincoln Laboratory.

Work is proceeding in collaboration with a contractor. A final design report has been written, and an implementation phase has begun. In at least one respect, namely, in the area of coherence in calling (see Sec. I-B above), the new design allows much more generality than do the present facilities on the TX-2 computer.

III. HUMAN INFORMATION PROCESSING

A. Stereoscopic Depth in Computer Generated Random Dot Patterns

When stereoscopic views are presented to both eyes asynchronously, stereoscopic depth can nevertheless be perceived when the display arriving first is dimmed sufficiently. It is possible to compensate for the asynchrony by making the elements comprising the leading display small with respect to those in the lagging display.

COMPUTER SYSTEMS GROUP 28

I. COMPUTER CENTER DEVELOPMENT

During this same quarter in 1966, Lincoln Laboratory began the task of converting its general-purpose computing load to the IBM System/360. Current statistics show that the level of production running of programs has increased over that of a year ago. The amount of check-out running has more than doubled, and the amount of systems programming and development work has expanded from a few hours crowded into an overburdened schedule to nearly a full shift per month. In spite of this increased activity, the turnaround time for work submitted by the general Laboratory user has been shortened by some 10 to 20 percent. This all results from the considerable increase in computing power provided by the dual processor main system and the efficiency of the multiprogrammed peripheral support computer.

Systems programming and development work continues in two categories. First is the constant correction and improvement of the batch monitor system in general Laboratory-wide use. One of the milestones of this past quarter has been the addition of a new and faster Fortran compiler. The second area of activity is that of on-line multi-access or time-sharing. We are now operating such a system for a few hours each day. It includes a Fortran compiler with a limited repertoire, especially in the input/output area, and is capable of supporting several remote terminals simultaneously.

Although no new components have been added, a printer was moved from the 360/67 to the 360/40. The former now has two printers, one for each central processor, while the latter now has three printers. This move provides increased off-line capability until such time as the main system is multiprogrammed to perform its own input/output work efficiently.

II. LISTAR (Lincoln Information Storage and Associative Retrieval System)

Over the past quarter, the LISTAR group has tested and modified the list-processing language *1 for use in coding LISTAR routines. The group has also written initial specifications for portions of the system, and has begun coding the principal system routines. The coding for the system may be divided roughly into four categories: routines for transferring files to and from auxiliary storage, routines for managing free space, routines for processing system commands from terminals, and routines for processing the files (i.e., searching, deleting, adding, etc.). Programs for performing operations falling into the first two categories are currently in preparation.

RADIO PHYSICS DIVISION 3

INTRODUCTION

This section summarizes the General Research efforts of Division 3 for the period 1 February through 30 April 1967. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary Report and the Quarterly Letter Report to the Advanced Research Projects Agency.

S. H. Dodd
Head, Division 3

M. A. Herlin
Associate Head

DIVISION 3 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1967

UNPUBLISHED REPORT

Meeting Speech*

MS No.

1840A The OH Radical in Radio M.L. Meeks Physics Seminar, Georgia Institute
 Astronomy

M.L. Meeks
Physics Seminar, Georgia Institute
of Technology, 12 April 1967

* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

SURVEILLANCE TECHNIQUES GROUP 31

Group 31 operates the Millstone Hill Field Station which includes the Millstone radar facility and the Haystack research facility. Research programs in satellite observation techniques and in ionospheric studies are conducted at Millstone. Radio astronomy and lunar studies programs are conducted at both Millstone and Haystack. During this quarter, planetary radar studies were centered at Haystack. Most radio astronomy observations at wavelengths 10 cm and longer are now at Millstone, thus complementing Haystack which is most appropriately used for observations at shorter wavelengths at which the capabilities of the 120-foot precision reflector are unique.

A non-linked OH spectral interferometric capability is being established between Millstone and the 140-foot telescope of the National Radio Astronomy Observatory (NRAO) at Green Bank, West Virginia, for study of as-yet-unresolved sources of OH line emission. A fully coherent X-band radar interferometer for deriving the reflectivity distribution over the disc of Venus is being established between Haystack and the 60-foot antenna of the Westford Communications Terminal. Work has also begun on the permanent establishment of a coherent radio interferometer capability between Millstone and the proposed 84-foot telescope to be available this fall at Harvard University's Agassiz Observatory. Installation of an S-band weather surveillance radar and of weather mapping modifications to the Millstone L-band system are in the final stages of completion, for use in the precipitation/propagation studies for the Space Communications Program.

I. GENERAL ENGINEERING IMPROVEMENTS

A. Millstone Radar Facility

1. L-Band Radar System

Transmitter, receiver, and data-processing modifications occasioned by the forthcoming space communications propagation studies are described in Sec. VI.

One receiving channel of solid state units has been constructed and checked out. It is hoped to provide additional channels in order that all of the outdated vacuum tube portion of the L-band receiver IF system can be modernized. Gain stability and ease of operation are major goals.

A coherent source has been provided at the L-band boresight tower for polarization checks of the variable polarization receiving system prior to performing lunar observations. Setup time is reduced by a factor of two.

A new target simulator was also designed and installed in the tracking data-processing system which permits a fast accurate check of the Doppler filter banks.

2. Radiometric Systems

Design has been completed and procurement started for a 10-foot-diameter rigid glass radome enclosure to be located behind the removable Cassegrainian subreflector on the tripod of

Division 3

the 84-foot antenna, for the purpose of sheltering parametric amplifiers and other radiometric front ends to be used with radio astronomy feeds located at the prime focus.

3. Millstone Computer Room

Installation of the SDS correlation filter equipment (CFE-1) on the SDS-9300 computer was finally completed in January with the addition of the priority interrupt required for the real-time use of this device. A fourth data subchannel was also installed at this time.

The installation of a rapid-access data file was completed early in March, but operable software to make the device usable will not be delivered before October 1967. The Station also still awaits delivery of a new basic 9300 software system which was promised 15 March.

A computer display was remoted to the ionospheric laboratory, the real-time operation of which is assisting substantially in ionospheric data-gathering operations.

B. Haystack Research Facility

1. Antenna System

During this quarter, the antenna has supported approximately 583.6 hours of radar and radio observations, with 134 hours set aside for antenna modifications and maintenance, and 6.4 hours of unscheduled down time. This does not include antenna hours reserved for instrumentation work connected with the radar system.

To reduce the tendency of failure in the present hydraulic drive motors, command rates have been restrained and the emergency closing of the blocking valves which serve as the antenna's only braking system has been decelerated.

A cable wrap status indicator has been built to permit the operator to select the proper azimuth zone for tracking. A servo-driven antenna position repeater is being built that will indicate angular position, control RF sector blanking to protect Millstone, control safe operation of the transmitter on the high-power test dock, and provide data for the cable wrap indicator. The RF box alignment fixture has been precision-mounted in the radome in a position such that the "travel lift" box carrier can place the box on the fixture, thus eliminating use of the antenna hoist as a work crane for this purpose. Provision has also been made to store this precision fixture on the Control Room roof, both to protect the fixture and to liberate floor area under the antenna.

Preparations are under way in support of the ultimate installation of cryogenic compressors on the Haystack antenna.

2. Active Systems

The Planetary Radar (PR) Box was on the Haystack antenna during the entire quarter and extensive radar operations on Venus, Mercury, and Mars, X-band radiometry, and lunar pulse mode mapping observations were carried out despite temporary setbacks resulting from transmitter tube failures, difficulties with the nitrogen/helium dewar containing the traveling-wave maser, and other problems.

Operations during most of February were performed using only a single VA-949AM klystron in the transmitter. A new tube, Serial No. 5, was installed in early March but failed after

less than 30 minutes of RF operation because of a longitudinal crack in a ceramic insulator. Single tube operation was resumed until mid-March, when Serial No. 2 was reinstalled, restoring approximately 300-kw operational capability.

A central console is being designed that will place a number of subsystems under direct control of the Test Director, thus reducing the number of manned operating stations required.

For most of this quarter, routine preventive maintenance and regular supplies of liquid nitrogen and helium served to maintain the maser front end of the planetary radar receiver in excellent operation at a system temperature on the order of 60°K. On 20 April, however, a rash of dewar troubles began with the failure of a VacIon pump and progressed to a cold leak in the operating dewar. When the spare dewar was installed, it appeared to exhibit a thermal short circuit in that, while the vacuum remained hard, helium consumption was extremely high, requiring refilling of the inner vessel at 4-hour intervals during planetary radar operations.

Division 7 is assisting in procuring a replacement inner vessel.

Work on a closed-cycle refrigerator to replace the dewar is in progress, and a number of the components have been delivered. If successfully tested and installed, the refrigerator will cool two masers, permitting dual-channel operation for reception of orthogonal polarizations by the planetary receiver system. However, this work, in which Division 7 is assisting, will require several months.

The PR maser and receiving system have been modified to permit operation in the radio-metric mode for radio astronomy.

3. Digital Data Systems

The direct data interface to the CDC 3300 computer is essentially complete unless new experiments require further changes. Two new modes of operation have been added: a high-speed A/D conversion mode for 5- μ sec pulse length lunar operations, and a mode which accepts an external digital input for transmission to the 3300 computer. The system is flexible in that it can handle a wide range of pulse widths and bandwidths. Mode changes can be accomplished quite rapidly, and several different types of experiment have been run regularly during a single day's operation.

Design and procurements to provide a new real-time clock arrangement for Haystack are well under way. The new unit is designed to eliminate time jitter problems associated with the present system.

A remote subconsole has been designed for control of the radar sequencer by the Experimental Test Director. This is a further step in the direction of centralizing the control of the operation Haystack system to reduce the number of manned operating positions during planetary radar experiments. Completion is expected in July 1967.

Design and procurements are well under way for a centrally controlled coordinator and interlock system which will make convenient the selection of different system configurations, while ensuring that all necessary subsystem protection requirements are automatically met.

C. Station Time and Frequency System

The primary hydrogen maser frequency standard failed at 0400 EST on 2 April, and had to be removed to the factory for repairs. Prior to that time, it had been operating with an absolute

Division 3

frequency stability of a few parts in 10^{12} relative to the primary hydrogen line frequency.

The Millstone site frequency standard is phase-locked to the primary Station standard located at Haystack, and a standby rubidium standard is also maintained at Millstone. A frequency error alarm system has been provided to warn of serious deviations of the standby from the primary standard.

Arrangements have been made which permit convenient phase stability tests to be made on the Haystack planetary receiving system prior to operations. RMS phase errors on the order of 1.5° are observed for periods up to 10 sec.

II. SPACE SURVEILLANCE

A. Computer-Aided Tracking

The precision orbit determination programs for the SDS-9300 are nearing operational status. Corrections made to the PREMOD* / MHESPOD† package have removed numerical discrepancies noted earlier when "successful" MHESPOD operations first began at Millstone. The latest MHESPOD revision, tested during eight different satellite passes, has yielded the best results to date in near real-time orbit upgrading. An updated orbit was fitted to the observations and the differences from predicted values were reduced to less than 6 km in range, 0.05° in angle, and 0.003 km/sec in Doppler after only two iterations.

The additional real-time programming required to permit computer steering of the antenna in the event of mid-track target loss should be ready for testing very shortly. The quality of the MHESPOD results suggests that it might be advantageous to steer the radar in Doppler as well as in angle and range, but hardware modifications will be required.

Raw tracking data can now be recorded on magnetic tape so that playbacks can be used for testing the orbital programs without requiring actual satellite tracks.

The Millstone non-real-time orbital program (NRTPOD) is also now running on the SDS-9300. It is substantially more sophisticated than the real-time system, and permits greater precision in orbit computation.

B. Tracking Support

Data from 45 passes of 16 selected objects of interest to the Space Defense Center were transmitted to the Center during this quarter.

Several operations were conducted to provide acquisition data for the Group 82 optical tracker located on Tower 3 at the Field Station.

One evening per week of tracking operations is also devoted to the MITRE/Millstone radar interferometer development.

* Preparation Module is non-real-time version of program used in initialization of MHESPOD.

† Millstone Hill (real-time version of) Electronic Systems Precision Orbit Determination Program.

III. LUNAR STUDIES

Details of the lunar studies program are reported in the fifth quarterly progress report to NASA, which was issued in February,* and in the sixth such report which is being prepared for a 15 May publication date.

A. Polarization and Mapping Studies at 23 cm

Contour maps of the polarized and depolarized returns from the moon have been constructed. The transmitted signal was circularly polarized. The effect has been explored of varying the fineness of the frequency resolution in the digital filtering employed in the signal processing.

The supersynthesis technique[†] has now been applied successfully to single range rings. For a given angle of incidence in excess of 40°, it has been found that the reflectivity, even on a scale of 200 km, may vary 5 db from one type of lunar terrain to another for the polarized component. For the depolarized component, the variation in reflectivity with terrain exhibited even higher contrast with differences as large as 10 db observed.

B. High-Resolution Radar Studies at 3.8 cm

By the end of the current reporting period, the entire region of the lunar surface lying between 16° latitude north and south, and 70° longitude east and west had been observed at 3.8 cm using the Haystack Planetary Radar in the pulse mode. A number of improvements in the overall data reduction and mapping system have been introduced in the last three months. In particular, we now have the capability of mapping as many as 190 range boxes in delay and 256 range boxes in frequency, several times more than previously possible. Along with this improvement has come the ability to display a map which has 200 × 200 resolution elements, an increase of a factor of 4 which better matches the delay-Doppler resolution now available. Finally, we now have the capability to take lunar maps using a delay resolution of 5 μsec, which means that in many areas of the lunar surface it is now possible to compete favorably with ground-based optical observations of the lunar surface.

IV. PLANETARY STUDIES

A. Radar Observations at 3.8 cm

During this quarterly period, the planetary effort has continued to be largely devoted to attempts to obtain precise radar measurements of Venus and Mercury echo delays and Doppler shifts using the Haystack Planetary Radar. In addition, ranging observations on Mars have been initiated, hopefully to lead to an improved understanding of the characteristics of the surface features as well as a more accurate determination of the orbit.

The best of the data obtained during the Mercury and Venus observations have yielded flight time accuracies on the order of ±10 μsec and Doppler determinations to better than ±2 Hz.

* Quarterly Progress Report No. 5, Radar Studies of the Moon, Lincoln Laboratory, M.I.T. (15 February 1967).

† Sometimes called the unambiguous mapping technique. This was described in Quarterly Progress Report No. 3, Radar Studies of the Moon, Lincoln Laboratory, M.I.T. (15 August 1966).

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Measurements to these accuracies must be obtained on Mercury and Venus over a relatively long period in order to fix the orbits with sufficient accuracy to permit a meaningful quantitative evaluation of the relativistic effects.

Cross-section measurements of Venus have been obtained using CW transmission while the subradar area on the planet was illuminated by the sun. These data will be correlated with photographs taken in ultraviolet light by workers at the Pic du Midi Observatory in southern France.

B. Planetary Radar Interferometer at 3.8 cm (Hayford)

An experiment has been proposed utilizing a 3.8-cm radar interferometer consisting of the Haystack Planetary Radar System combined with the Westford 60-foot antenna system operating in the receive mode, aimed at determining with higher resolution than previously possible the general distribution of surface reflectivity across the disc of Venus. With the data to be obtained, it is hoped to narrow down the number of acceptable surface and atmosphere models that have been proposed to explain the previous observations of that planet.

The overall design of the system has been completed, and the major system blocks are under construction. The heliax intersite coupling cable is on order, and the phase-stabilizing servo system designed to compensate for temperature-induced changes in effective cable length is also under construction.

It is planned to begin testing the complete system in July aimed at an intensive observing period the last two weeks in August, near the forthcoming inferior conjunction of Venus.

V. ATMOSPHERIC STUDIES

A. Thomson Scatter*

A weekly series of 12-hour nighttime backscatter runs constituted a search for the predawn electron temperature increase thought to result from solar heating of the geomagnetic conjugate point. On 24 and 25 April, a 30-hour continuous backscatter run was conducted to cover a period when several ionospheric rocket probes were launched by the University of Michigan from Cape Kennedy. Data from these runs are being prepared for transmittal to Professor Nagy at the University.

Design and construction are in progress on a tapped delay-line filter-bank analog spectrum analyzer to permit simultaneous derivation of power spectra at a number of different heights essentially in real time. This machine will be interfaced to the computer for recording and display of the spectral data. If successful, this will overcome the most serious bottleneck in the analysis of backscatter data.

To provide an improved method of gathering E-region data at 100- to 200-km heights, a so-called "2-pulse" arrangement is being implemented for the UHF ionospheric radar system. This scheme employs short pulses alternately reversed in polarization and progressively separated in time to permit one to develop the correlation function of the backscattered signal from which the power spectrum may be derived. The scheme permits much improved height resolution without sacrificing frequency resolution. The tentative completion date for both of the above system additions is 1 September 1967.

* Formerly referred to as ionospheric backscatter.

A competing method of rapidly obtaining the power spectra at different ranges from back-scatter data is full digital analysis using the CFE-1 correlation and filtering equipment connected to the SDS-9300. A non-real-time program to test this method has been run successfully using simulated data. The regular ionospheric data-gathering program is being modified to permit recording of actual data samples for testing this new method. Experience with this method of signal processing is expected to be valuable in the future in several applications.

B. Auroral Studies

Because of an equipment malfunction undetected when the data were initially processed to obtain the auroral echo spectra, it will be necessary to reprocess a quantity of data. Recent reprocessing of some of these data yielded a picture tending to confirm Bowles' theory of an auroral electrojet.

VI. RADIO ASTRONOMY

A. Instrumentation

A separate pump klystron was installed in the Haystack PR Box to permit the Planetary Radar maser to be used at 7795 MHz and has improved the system stability for radio astronomy observations. However, still under study is a small amount of baseline curvature noted in spectral observations after several hours of integration.

The Radiometer Box (R-Box) was moved from the standard gain horn at the rear of Haystack to the test dock under the radome to prepare the R-Box for return to the Haystack antenna in June. A major improvement is the installation of a new cone for supporting primary feeds and other microwave equipment at the front of the R-Box. Change of radiometric feeds while the R-Box is on the antenna will be greatly facilitated.

After completion of the spectral line observations at 1303 MHz on 23 April, the radiometer system was removed from the Millstone antenna. It is being repackaged and will be reinstalled as part of the program for improved radio astronomy instrumentation for the Millstone 84-foot antenna.

Work on the permanent, or "Phase 2," Millstone-Agassiz interferometer included:

- (1) Selection of a design for a two-way phase-stable microwave link.
- (2) Packaging of an OH line parametric amplifier to be used in the previously mentioned temperature-controlled protective enclosure to be installed at the prime focus of the Millstone antenna.

The Phase 2 system should be ready in the fall of 1967, by which time Harvard is scheduled to have completed the substitution of an 84-foot dish, similar to the one at Millstone, for the present 60-foot reflector on the Kennedy mount at Agassiz Station. This system should provide an important new observing capability to the Lincoln/M.I.T./Harvard radio astronomy community.

Equipment designs have been completed and construction is under way for a non-linked interferometer which will be operated between the Haystack or Millstone antenna and the 140-foot antenna at NRAO, Green Bank, West Virginia. Operation without an intersite phase-synchronizing link depends vitally on highly stable frequency standards at each station. Phase-coherent data

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will be digitized and recorded on magnetic tape at each station, and the tapes will then be cross-correlated on the Haystack CDC 3300. The system, operating at 1665 MHz, will be scheduled for operation for 3-day periods in early and late June and again for similar periods in August. The June periods will make use of the Haystack antenna, while in August the Millstone antenna will be employed. Lincoln Laboratory, M.I.T., and NRAO scientists are jointly interested in the results of this venture in which resolution of the highly polarized OH sources in Westerhout 3 will be attempted. As reported previously,* the Millstone-Haystack and Millstone-Agassiz (≈ 13.7 -km baseline) interferometers have failed to resolve these sources.

B. Continuum Observations

Observations of continuum radio emission using the Planetary Radar receiver system at frequencies near 7.8 GHz included mapping of a 1° square centered on the Orion nebula and mapping of the region of the above-mentioned galactic radio source Westerhout 3, from which anomalous OH emission has been pinpointed. The Orion map was prepared in conjunction with observations of the microwave recombination lines in this source as described in Sec. C. below. The Westerhout 3 map disclosed a weak continuum source, previously not detected, at the position of the OH emission. This continuum source may represent an energy source that pumps the OH cloud to produce maser action which is thought to account for the strong OH spectral-line emission at 18-cm wavelength.

Observations of the flux of time-varying extra-galactic radio sources (quasars and peculiar galaxies) are continuing. The source 3C84 continues to increase slowly in flux, 3C273 is now decreasing, 3C279 is leveling off after a previous increase, and the weak source 3C345 may be increasing rapidly.

C. Spectral Line Observations

Almost all observations of the microwave recombination lines have been made in the neighborhood of the Orion nebula. The radiometric map of this region at 7.8 GHz shows that the nebula is partly resolved with a 4.2-minutes-of-arc beam, and the optical nebula NGC 1982, which appears to be attached to the Orion nebula, is resolved as a separate radio source. Observations of the radial velocity distributions within these radio sources were made by observing the hydrogen recombination line (94α) which has a frequency of 7793 MHz. The helium recombination line (94α) at 7796 MHz was observed with long integration times to examine carefully the line shape, which was previously reported to be asymmetric. After precise measurements and examination of the theoretical recombination spectrum, it was concluded that the apparent asymmetry of the helium line is a result of partial overlap of the 94α helium line and a 148δ hydrogen recombination line at 7797 MHz. If the nebular plasma is in local thermal equilibrium, then the 148δ line would be expected to appear at about the observed strength.

* General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 February 1967), DDC 650401.

VII. SPACE COMMUNICATIONS

A. Propagation Studies

A program of experiments to determine the effect of precipitation on X-band propagation paths between a ground station and a satellite is planned for this summer, to be conducted jointly with Division 6. The Westford site will directly measure path losses from emitting satellites, while Millstone and Haystack will characterize the precipitation by radar and radiometric measurements, respectively.

1. Instrumentation Progress

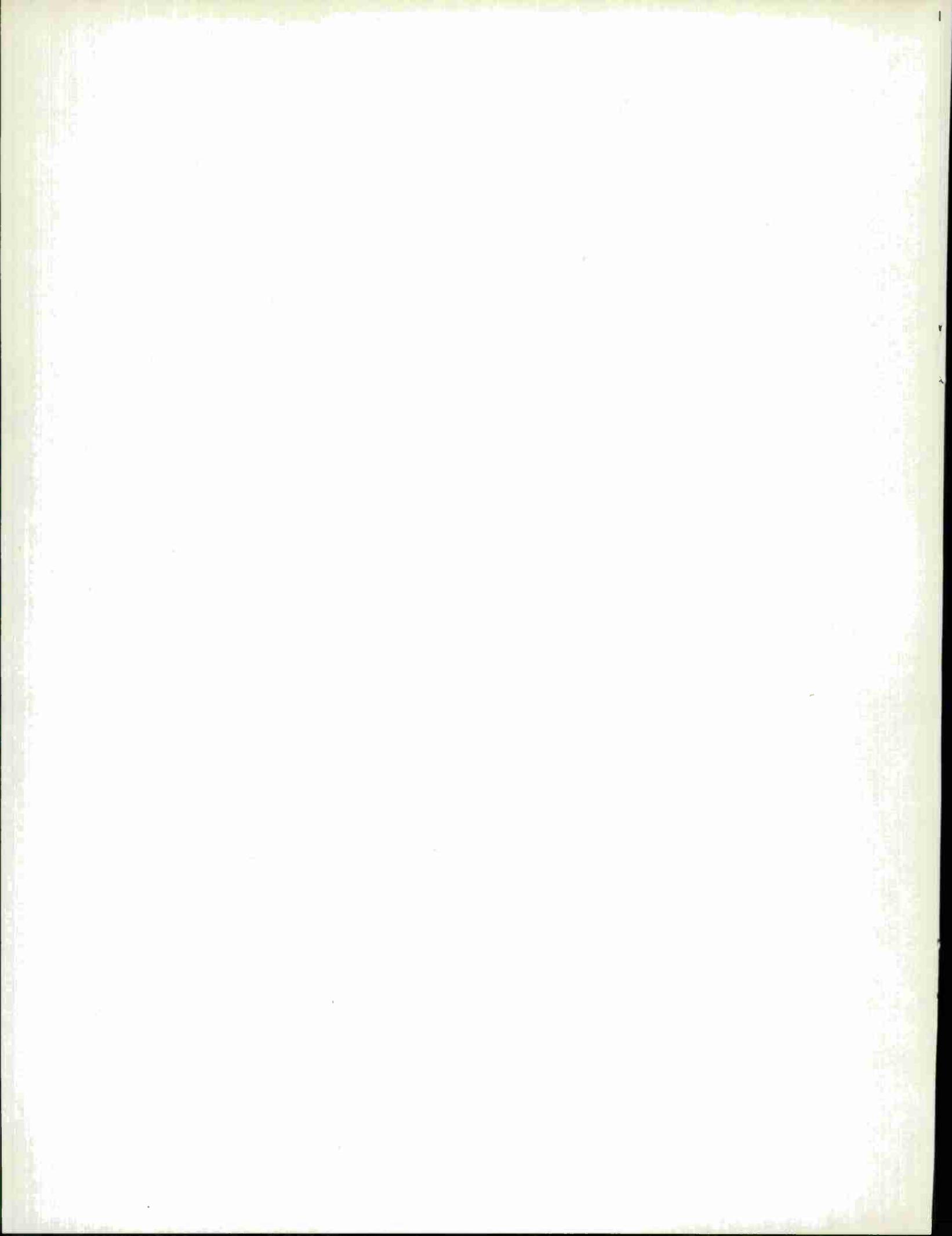
a. FPS-18 Radar – Weather Surveillance

Installation of an FPS-18 S-band radar in the Millstone warehouse, which began during the last week of the previous reporting period, has been completed. The radar has been operated into a dummy load at full power. The radar antenna has been installed on a 54-foot tower near the northwest corner of the building. A closed-circuit television system has been provided for remote viewing of the PPI display in the control rooms at Millstone and Westford.

b. Modifications to L-Band Radar

Near the end of this quarter, a new tail clipper circuit for the klystron FPA modulator was designed on-site and installed. Construction of a companion "ON-box" was begun. These modifications will permit short-pulse, high-PRF operations needed in the propagation studies experiment without sacrificing the long-pulse capability required for satellite tracking and planetary radar studies.

Design and construction are under way on broad-band phase detectors and on data-processing arrangements required to handle the high-data rate output from the radar when operating in the short-pulse mode.



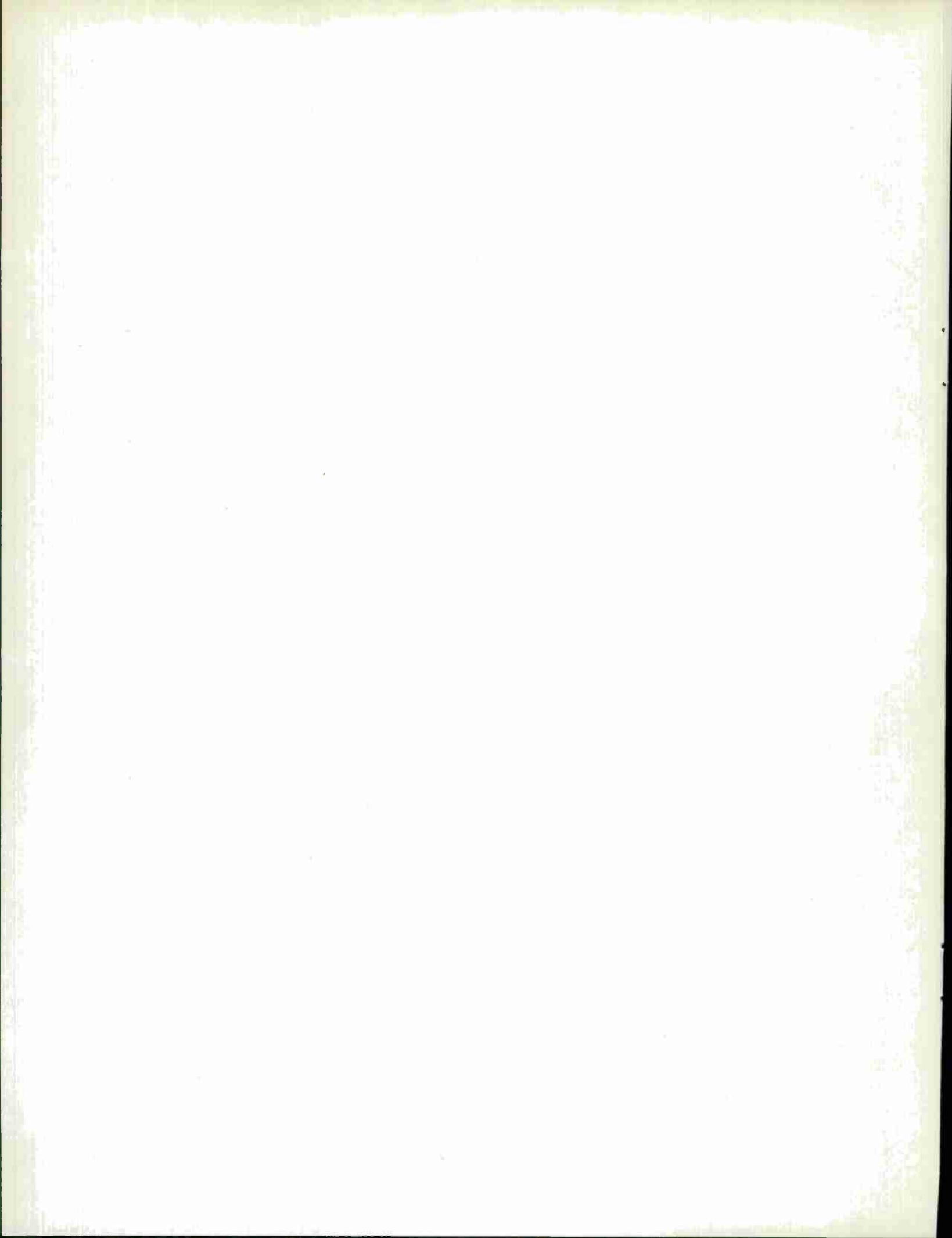
RADAR DIVISION 4

INTRODUCTION

This section summarizes the General Research activities of Division 4 during the period 1 February through 30 April 1967. The major portion of Division 4's activities is devoted to Radar Discrimination Technology, PRESS, BMRS, Space Communications, and Radar Studies of the Moon, which are described in separate reports. The General Research activities in Division 4 are carried out by Group 46, which is engaged in work on Haystack instrumentation and microwave techniques studies.

J. Freedman
Head, Division 4

H. G. Weiss
Associate Head



MICROWAVE COMPONENTS GROUP 46

I. INTRODUCTION

Group 46 contributes to the radar program through direct participation in specific projects, and through a program of general research which is closely related to the microwave requirements arising from radar projects. Contributions are made to the General Research Program through the support of Haystack Hill, operation of a high-power microwave laboratory, development of low-noise receiver techniques, studies of very-high-gain antennas and antenna feeds, and participation in a millimeter-wavelength program. The latter is reported separately under Radar Studies of the Moon.

II. HAYSTACK MICROWAVE COMPONENTS

A. Planetary Radar (PR) Box

The high-power circulators are ready for installation, and the layout of the waveguide run for the through-sum receiver channel is being determined.

A "breadboard" model of an insertion loss test set which employs bolometers and a ratio transformer* has been constructed and used to measure the losses of PR Box waveguide components. Two units will be built for general laboratory use.

Measurements have been made on various makes of X-band waveguide switches. These measurements show that most of the insertion loss is due to the gap between the rotor and stator. A resonance method has been adapted for use in measuring these gap losses, and results have shown that it should be possible to reduce the switch loss to a value close to the waveguide wall loss. In an attempt to reduce the gap loss, a switch employing a new type of choke is being developed.

B. Model Study of an L-Band Feed

Preliminary measurements on the 1/20 scale model of the Haystack antenna indicate that the loss in gain at L-band is partly due to incorrect focusing of the Clavin feed. To compensate for the phase error resulting from near-field operation, it appears that the Clavin feed must be defocused toward the dish vertex. This is opposite the direction that a feed is usually defocused for near-field measurements.

Since no reduced-scale version of the Clavin feed was available, a dielectric lens fed by a small horn was used to simulate the existing L-band feed at Haystack. The lens is sufficiently different from the Clavin feed that the results cannot be used to make quantitative predictions. A scale model of the Clavin feed will be available at a later date.

Two other feeds were included in the scale-model measurements: the first was a large and very long horn in place of the lens feed, and the second was a small horn used together with a special subreflector of low magnification to obtain a far-field Cassegrainian geometry. The gain

* C. J. Finnie, D. Schuster, and T. Y. Otoshi, "AC Ratio Transformer Technique for Precision Insertion Loss Measurements," Technical Report 32-690, Jet Propulsion Laboratory, California Institute of Technology (30 November 1964); D. White, "AC Ratio Transformer Insertion Test Set," Space Programs Summary 32-27, Vol. IV, Jet Propulsion Laboratory, California Institute of Technology (30 June 1964), pp. 165-167.

Division 4

of the antenna with the large horn was about 1 dB less than that achieved with the far-field geometry. Use of a parabolic subreflector and reduction of the horn-to-subreflector distance to one-half the Haystack distance increased the gain with the large horn, but it remained about 0.5 dB below the far-field case.

C. Masers

The Air Products and Chemicals, Inc. closed-cycle helium refrigerator has been delivered to the Haystack site. Soldering problems have been encountered in assembling the superstructure to which two masers will be attached. Steps are being taken to resolve these problems.

III. SOLID-STATE COMPONENTS

A. X-Band Parametric Amplifier

The addition of a broadbanding stub to the low-noise parametric amplifier increased its bandwidth by a factor of about $2\frac{1}{2}$, as mentioned in the preceding quarterly report, but raised the noise temperature from 105° to 135°K . This increase was not unexpected; it is caused by the losses in the relatively high-Q broadbanding resonator. An additional stub is being added to increase further the bandwidth of the amplifier.

B. Diode Measurements

The resonance technique for the measurement of the impedance of packaged diodes in waveguide was found to have excessive error in the frequency range from 18 to 40 GHz. A new technique for direct impedance measurement in a radial transmission line has been conceived and is being investigated. This method is expected to eliminate the largest of the errors associated with the waveguide technique.

Use of the Mavaddat* technique for the determination of the cutoff frequency of commercially available varactor diodes in a waveguide mount has continued. Measurements at 11 GHz yielded results that are in close agreement with those obtained from measurements in a coaxial line at 8.12 GHz. Additional measurements will be made by the Mavaddat technique at 35, 45, 55, 70, and 100 GHz.

C. Power Combiners

One method of circumventing the power limitation on solid-state microwave sources is to combine the output power from many such sources. In the past, circuit techniques for combining power have been physically large and limited to only a few diodes. A new method for power combination has been devised that distributes the diode sources on an equiphase surface of a conical transmission line, and allows many diodes to be treated electrically as though they were just one diode of high-power capacity. Using this technique, it should be possible to combine the power from 1000 diodes in a spherical structure of about 6 inches in diameter.

A low-frequency (2-GHz maximum) version of such a power combiner is being constructed. It uses 18 diodes and will be tested as a large-signal doubler from 500 to 1000 MHz. A high-frequency (4-GHz band center) version of the power combiner is being designed which will employ 36 diodes and be tested as a large-signal multiplier and up-converter with appropriate external circuitry.

* R. Mavaddat, "Varactor Diode Q-Factor Measurements," J. Electron. Control 15, 51 (July 1963).

ENGINEERING DIVISION 7

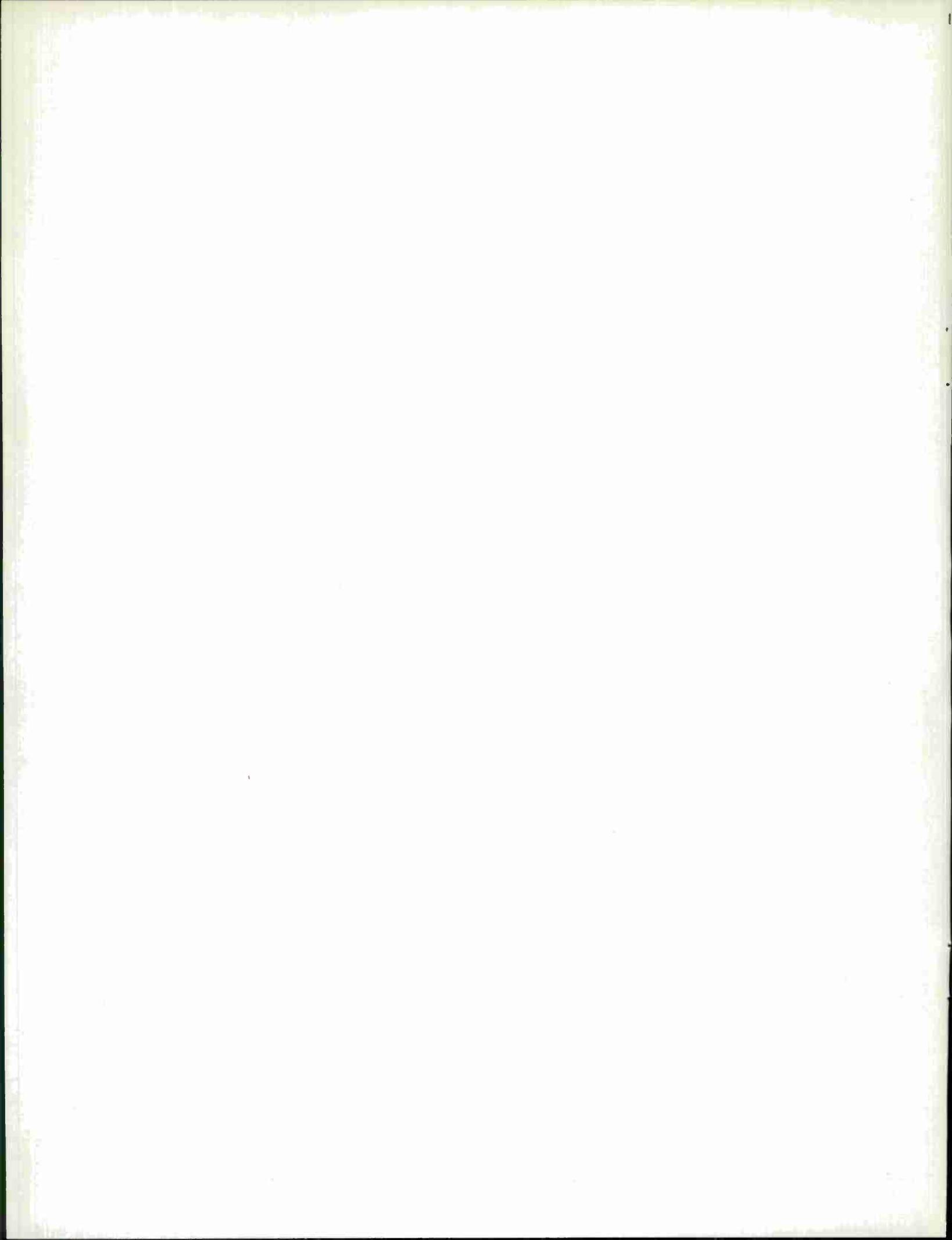
INTRODUCTION

In the quarterly period ending 30 April 1967, the Engineering Division supported the Laboratory's General Research Program principally by working on components of the Haystack and Millstone antenna systems, by continuing its studies of the proposed CAMROC radome and antenna configurations, and by designing a crystal-growing apparatus for solid state research.

At Haystack, work is continuing on the microwave plumbing system of the Planetary Radar(PR) Box to reduce sources of contamination, and a newfeed system for the radiometer box is being fabricated. Improvements are also being made on the Laboratory-developed hydraulic servo control valve.

The CAMROC study group has selected a vertical-truss design concept for the reflector configuration. Meanwhile, considerable effort is continuing to optimize the radome design via configuration studies and structural analyses.

J. F. Hutzenlaub
Head, Division 7



MECHANICAL ENGINEERING GROUP 71

I. HAYSTACK

A. Planetary Radar Box

1. Microwave

VA-949 klystron tube changes were made on 27 February and 10 March 1967 while the PR Box was on the antenna by using the special tube-handling vehicle.

Evaluation of contamination difficulties experienced during the copper electroforming process is continuing. In addition, a mode generator is being fabricated by Stanford Linear Accelerator Center, Stanford, California.

2. Maser

The second maser has been assembled onto its microwave head and is currently undergoing evaluation tests at Haystack. This unit will operate in a batch dewar and will be available for standby operation for the number one maser, which has been operating in the PR Box since September 1966. The third maser is to be integrated in the closed-cycle refrigerator which is being readied for the antenna. The support stand for the cryostat and compressor dolly has been completed.

B. Antenna

The CO₂ fire extinguisher system was installed at the box antenna position and at the inside test dock. The outside test dock installation will be performed at a later date. A monorail hoist has been installed and catwalk modifications have been made on the right side of the box antenna position. This equipment, together with a 3-wheel dolly, will be used to install and service the closed-cycle refrigerator compressor.

An additional stow hole in each of the elevation sector gears to position the antenna $7\frac{1}{2}^{\circ}$ from the horizon is being provided.

C. Radiometer Box

Fabrication has begun on a scheme to replace the tapered single-feed front section of the radiometer box with a cylindrical multifeed section. Five fixed reflectors will be mounted on the front face of this section and, in addition, a 90-inch-diameter L-band reflector will be positioned in front of the five reflectors. The L-band reflector, when not in use, will be moved on rails by means of a mechanical drive and stowed to one side, thus exposing the fixed reflectors for operation.

Installation and testing should be completed by mid-June 1967, when the radiometer box will be mounted on the antenna.

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II. MILLSTONE

A. 84-Foot-Diameter Tracker

Fabrication has begun on a 10-foot-diameter equipment enclosure to be mounted on the apex platform above the secondary reflector. The enclosure will be a spherical urethane-insulated fiberglass radome, with a personnel door accessible from the spar ladder. A 3-ton chiller unit will be mounted on the front azimuth platform supplying cooled air to two fan-coil heat exchangers located in the apex enclosure. Strip heaters and controls will also be used to maintain a constant temperature within $\pm 5^{\circ}\text{F}$.

B. 220-Foot Zenith Antenna

Equipment is being procured and fabrication has begun on the installation of a WR-2100 waveguide receive line from the antenna to the transmitter building. A second duplexer assembly will be installed, necessitating an addition to the existing equipment enclosure located under the 220-foot antenna.

III. SOLID STATE

A. Bridgman Type Crystal-Growing Apparatus

The technique of lowering a tapered crucible through a furnace is known as the Bridgman-Stockbarger method for growing crystals. An apparatus with a lowering rate of $1/32$ to 1 inch an hour has been designed and manufactured for this purpose. Vacuum or controlled atmosphere melting can be performed with this equipment.

B. Laser Crystal Housing

A housing has been designed for the testing of new continuous-wave laser materials. Its performance is independent of crystal length. The housing consists of an aluminum box into which the laser aggregate is positioned by an adjustable crystal holder contained in a glass-jacketed chamber for cooling purposes.

The water-cooled laser crystal is energized by means of one 900-watt air-cooled iridium light.

IV. CAMROC

A. Radome Studies

1. Structural

The effect of the membranes in preventing column instability of the beam members in a plane tangent to the surface of the radome is under investigation. If the membranes are sufficiently strong and can be adequately secured to the beams so that the membranes constitute a major structural component of the radome, then narrower beams can be utilized for the space frame. Because the optical blockage of the radome framework is most sensitive to the beam width, any decrease in this dimension will substantially improve the performance of the system.

In addition to the membrane studies, we are investigating the use of plastic lines in minimizing column buckling when connected between beam members in a triangular cell.

2. Computer Program

The STAIR computer program has been converted to the Lincoln Laboratory IBM/360 computer system. STAIR has been used to determine the axial forces developed in the beam members of two uniform space-frame geometries by assumed wind loads on the 550-foot-diameter radome. The first geometry contained 825 beams with an average beam length of 55 feet; the second geometry contained 1845 beams with an average beam length of 37 feet. These results can be expressed in nondimensional form and used to determine, to a good approximation, the axial loads in any spherical space-frame radome structure.

With the axial loads precisely established for a given geometry and the transverse loads readily obtained, a beam column analysis can be performed to determine the minimum acceptable beam dimensions. Several iterations of this cycle and the precise cross-sectional dimensions for each beam are readily obtained. A computer program utilizing this technique is in preparation, and some preliminary results have been obtained.

3. Radome Configurations

A radome which is hemispherical down to the equator and cylindrical from the equator to the base is currently under investigation. The critical buckling pressures, membrane stresses, and the discontinuity stresses at the equator and the base will be calculated and a report prepared. A similar investigation will be conducted with the cylindrical portion of the radome replaced by a conical frustum. Finally, the advantages of utilizing either cylindrical or conical frustum sections for short distances from the base to the sphere proper will be studied.

4. Instability

a. Analytical

The formulation of the governing nonlinear equations required to determine the load deflection relationship for an arbitrary space-frame structure exposed to an arbitrary loading has been completed, and the equations have been programmed for the IBM/360 computer. Initial runs on sample structural problems have been successful. The program is now being test run on larger frame sections at Lincoln Laboratory, and it is anticipated that the program will be operational within the next quarterly period. These programs are being developed jointly by personnel from Simpson, Gumpertz & Heger and the Civil Engineering Department at M.I.T. under the supervision of Lincoln Laboratory.

b. Experimental

A spherical, random geometry, space-frame radome section, 14 feet in diameter with a central angle of 104°, has been designed, fabricated, constructed, and instrumented under the supervision of the Aeroelastic and Structures Research Laboratory at M.I.T. The behavior of the model has been checked through preliminary load tests. It is anticipated that buckling tests will commence in May 1967.

B. Antenna Studies

A review and evaluation of the various possible antenna configurations for CAMROC have been completed. Since cost differences for all five of the concepts under study were small, the selection of the favored reflector configuration was based primarily upon considerations of performance, technical risk, growth capability, and experimental equipment flexibility.

In accordance with the above considerations, it appeared that the vertical truss concept with either open-loop or passive compensation would be the best choice for CAMROC. Of the two studies which embodied this concept, the general arrangement of the Hammerhead design was more desirable. It may develop in future studies that some form of hybrid between the two studies may evolve as a final design. The salient factors leading to this choice are summarized below.

- (a) Compensation for distortions of the primary reflector due to gravity is simpler to apply to the less redundant vertical truss design of Hammerhead. The structure is basically a two-dimensional system making analysis and application of compensating elements more predictable and accurate.
- (b) The doubly cantilevered Hammerhead truss can be utilized in the erection of the radome and is quite compatible with the overall erection plan of the antenna and radome.
- (c) A relatively large non-tilting experimental laboratory can be located immediately behind the vertex of the primary reflector. The volume of space far exceeds projected requirements and is thus capable of accommodating future expansion if required.
- (d) The economical fabrication techniques employed in this type design not only offer realistic cost savings, but allow for easy adjustment of the component parts.

Accordingly, plans are being made to proceed with the next phase of the program based upon utilizing the vertical truss concept as the required antenna configuration. Engineering and design efforts will be involved in producing a series of design control drawings and accompanying specifications that will be included in the final contract documentation for the design of the 440-foot-diameter radio telescope. The target date for completion of this work is 1 December 1967.

PHYSICAL PLANT ENGINEERING GROUP 75

I. INFRARED TRACKING TOWER AT MILLSTONE

This project consists of a reinforced concrete tower located 380 feet westerly from the Millstone Hill Radar Observatory. It will support a Nike-Ajax antenna pedestal. The tower is a reinforced concrete structure supported and doweled into bedrock for stability. This structure is approximately 21 feet in height above finish grade and is a six-sided regular polyhedron whose diameter is 15 feet 2 inches.

An intermediate deck is located 8 feet above the finish floor and is used as a service platform for the antenna pedestal. At the top of the tower is a removable metal-clad deck through which the mount projects.

Around the top of the structure is a cantilevered walkway with a removable safety handrail. Electrical power will be obtained from a power panel located on Tower 3 which is located approximately 90 feet away in an easterly direction.

An interior stairway will provide access for personnel to the top of the tower. For material and equipment, a power-operated telescoping platform will be installed. A folding convertible type canvas housing has been designed to enclose the mount when it is not in operation. Proposals for the vertical hoist and the canvas housing are being prepared. These items should be available by the time the basic construction work is completed.

The project is presently in the construction stage and it is anticipated that work will be completed on or about 1 June 1967.

CONTROL SYSTEMS GROUP 76

I. MILLSTONE RADAR

During this quarterly period, design of a celestial-to-terrestrial coordinate converter was completed. Mechanical and electrical assemblies, now half finished, are expected to be completed in time for testing and delivery to Millstone by 1 July 1967. This converter is expected to have one-sigma errors of 0.01° when used against targets at infinite range. Means are provided for remote switching of predetermined offsets to declination, right ascension, azimuth, and elevation.

II. HAYSTACK

A. Hydraulic Control System Development

Instrumentation necessary for evaluation of the Laboratory-developed servo valve was assembled and connected. Relations between main spool friction, flow reaction forces, load pressures, flow, and spool travel were established and plotted. As a result of these tests, the following modifications to the valve are being accomplished: (1) an increase in first-stage flapper valve spring force and rework of orifice to reduce control current offset; (2) an addition of compensation to provide increased low-frequency gain; and (3) a change in shape of main spool orifice to improve flow control resolution.

B. Reflector Measurement and Rerigging

The final report on the rerigging study by Simpson, Gumpertz & Heger has been completed. The report utilizes a statistical approach to antenna measurement data reduction and analysis and gives a more efficient and realistic result than approaches used in the past. It includes details of programming used for this approach.

Recent photographic tests of scale target measurements for the photographic reflector measurement system have yielded encouraging results. Implementation in the full-scale system is proceeding.

III. LUNAR RADAR

A proposal for a data recording system was submitted to Group 46 (Microwave Components) for approval. The system will provide means for recording on punched cards, information about pointing angles, date, time, event, polarization, power output, and background and calibration returns. Equipment to be designed and manufactured by Group 76 includes the punch control unit, event counter, and digital clock.

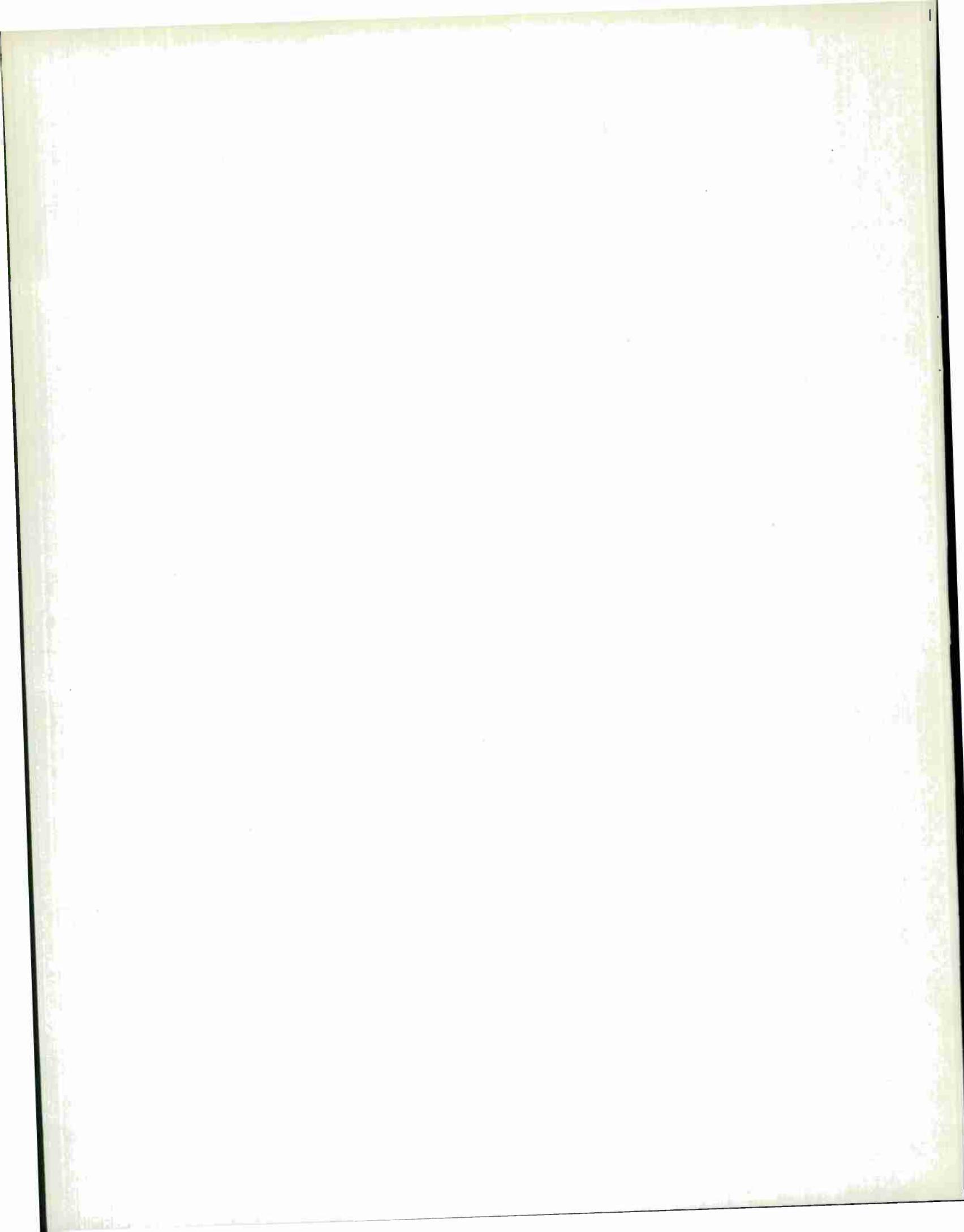
SOLID STATE DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 February through 30 April 1967. A more detailed presentation is covered by the Solid State Research Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head



DIVISION 8 REPORTS ON GENERAL RESEARCH

15 February through 15 May 1967

PUBLISHED REPORTS

Journal Articles*

JA No.

2581	Magnetic Quantum Effects	P. N. Argyres L. M. Roth†	Semiconductors and Semimetals, Vol. 1 of Physics of III-V Compounds, edited by R. K. Willardson and A. C. Beer (Academic Press, New York, 1966)
2747	Space-Time Symmetry Restrictions on Transport Coefficients. II. Two Theories Compared	W. H. Kleiner	Phys. Rev. <u>153</u> , 726 (1967)
2796	Comparison of the Theoretical O ⁻ Form Factors with Experiment	P. M. Raccah R. J. Arnott	Phys. Rev. <u>153</u> , 1028 (1967), DDC 651719
2837	Low Temperature Crystallographic and Magnetic Study of LaCoO ₃	N. Menyuk K. Dwight P. M. Raccah	J. Phys. Chem. Solids <u>28</u> , 549 (1967)
2872	A First-Order Localized-Electron \rightleftharpoons Collective-Electron Transition	P. M. Raccah J. B. Goodenough	Phys. Rev. <u>155</u> , 932 (1967)
2873	Hartree-Fock Theory: Slater Determinants of Minimum Energy	T. A. Kaplan W. H. Kleiner	Phys. Rev. <u>156</u> , 1 (1967)
2875	Virial Theorem for the Homogeneous Electron Gas	P. N. Argyres	Phys. Rev. <u>154</u> , 410 (1967)
2878	Low Temperature Absolute Reflection Measurements of Small Samples	J. Feinleib B. Feldman	Rev. Sci. Instr. <u>38</u> , 32 (1967)
2887	Spark-Source Mass Spectroscopy	E. B. Owens	Appl. Spectroscopy <u>21</u> , 1 (1967)
2890	Interband Magneto-optical Studies of Semiconductors and Semimetals	B. Lax† J. G. Mavroides	Appl. Optics <u>6</u> , 647 (1967)
2903	Excitation Spectra of Group III Impurities in Germanium Under Uniaxial Stress	D. H. Dickey J. O. Dimmock	J. Phys. Chem. Solids <u>28</u> , 529 (1967)
2918	Semiconductor-to-Metal Transitions in Transition-Metal Compounds	D. Adler† J. Feinleib H. Brooks† W. Paul†	Phys. Rev. <u>155</u> , 851 (1967)

* Reprints available.

† Author not at Lincoln Laboratory.

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JA No.

2920	Semiconductor-to-Metal Transition in V_2O_3	J. Feinleib W. Paul*	Phys. Rev. <u>155</u> , 841 (1967)
2921	On the Thermodynamic Properties of Several Solid Phases of the Compound InSb	A. K. Jena* M. B. Bever* M. D. Banus	Trans. Met. Soc. <u>239</u> , 725 (1967)
2923	Diode Lasers of $Pb_{1-y}Sn_ySe$ and $Pb_{1-x}Sn_xTe$	J. F. Butler A. R. Calawa T. C. Harman	Appl. Phys. Letters <u>9</u> , 427 (1966)
2927	Polaron Effects in the Cyclotron-Resonance Absorption of InSb	D. H. Dickey E. J. Johnson D. M. Larsen	Phys. Rev. Letters <u>18</u> , 599 (1967)
2928	Temperature-Modulated Reflectance of Gold from 2 to 10 eV	W. J. Scouler	Phys. Rev. Letters <u>18</u> , 445 (1967)
2932	High Power and Efficiency in CdS Electron Beam Pumped Lasers	C. E. Hurwitz	Appl. Phys. Letters <u>9</u> , 420 (1966)
2946	InSb MOS Infrared Detector	R. J. Phelan, Jr. J. O. Dimmock	Appl. Phys. Letters <u>10</u> , 55 (1967)
2948	The Electrical Properties and Band Structure of Doped $LaInO_3$	D. B. Rogers* J. M. Honig J. B. Goodenough	Materials Res. Bull. <u>2</u> , 223 (1967)
2965	Identification of the Fundamental Vibrational Modes of Trigonal, α -Monoclinic and Amorphous Selenium	G. Lucovsky* A. Mooradian W. Taylor* G. B. Wright R. C. Keezer*	Solid State Commun. <u>5</u> , 113 (1967)
2988	Raman Scattering from Donor and Acceptor Impurities in Silicon	G. B. Wright A. Mooradian	Phys. Rev. Letters <u>18</u> , 608 (1967)

MS No.

1422	Theory of the Method of Kinetic Equations for Quantum Systems	P. N. Argyres	Lectures in Theoretical Physics, Vol. 8A (University of Colorado Press, 1966)
1702	Optical and Laser Properties of Nd^{+3} - and Eu^{+3} -Doped YVO_4	J. R. O'Connor	Trans. Met. Soc. <u>239</u> , 362 (1967)
1746	Dependence of Critical Properties of Heisenberg Magnets upon Spin and Lattice	H. E. Stanley T. A. Kaplan	J. Appl. Phys. <u>38</u> , 977 (1967)
1747	On the Possible Phase Transition for Two-Dimensional Heisenberg Models	H. E. Stanley T. A. Kaplan	J. Appl. Phys. <u>38</u> , 975 (1967)

* Author not at Lincoln Laboratory.

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MS No.

1791	Spontaneous Band Magnetism	J. B. Goodenough	J. Appl. Phys. <u>38</u> , 1054 (1967)
1814-II	Characterization of d Electrons in Solids by Structure. II. Spontaneous Crystallographic Distortions	J. B. Goodenough	Materials Res. Bull. <u>2</u> , 165 (1967)
1815	Experimental Techniques with General Applicability for the Study of Magnetic Phenomena	K. Dwight	J. Appl. Phys. <u>38</u> , 1505 (1967)

* * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.

2850	High-Temperature Expansions for the Classical Heisenberg Model. I. Spin Correlation Function	H. E. Stanley	Accepted by Phys. Rev.
2907	High-Temperature Expansions for the Classical Heisenberg Model. II. Zero-Field Susceptibility	H. E. Stanley	Accepted by Phys. Rev.
2939	Fourier Expansion for the Elec- tronic Energy Bands in Silicon and Germanium	G. F. Dresselhaus M. S. Dresselhaus	Accepted by Phys. Rev.
2964	Temperature Dependence, Orienta- tion Correlation and Molecular Fields in Second Harmonic Light Scattering from Liquids and Gases	D. L. Weinberg	Accepted by J. Chem. Phys.
2973	The Crystal Structure of Neodymium Monotellurooxide- $\text{Nd}_2\text{O}_2\text{Te}$	P. M. Raccah J. M. Longo H. A. Eick*	Accepted by Inorg. Chem.
2975	Report on the Seventh Inter- national Conference on the Physics of Semiconductors	B. Lax* J. G. Mavroides	Accepted by Phys. Today
2977	Interband Magnetoreflection and Band Structure of HgTe	S. H. Groves R. N. Brown* C. R. Pidgeon*	Accepted by Phys. Rev.

* Author not at Lincoln Laboratory.

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JA No.

2978	Magnetoplasma Cyclotron Absorption in PbSe	S. Bermon	Accepted by Phys. Rev.
2989	A Thermodynamic Investigation of the Compounds In_3SbTe_2 , InSb and InTe	A. K. Jena* M. B. Bever* M. D. Banus	Accepted by Trans. Met. Soc. AIME
2993	Magnetic and Structural Study of the Spinel MnYb_2S_4	J. M. Longo P. M. Raccah	Accepted by Materials Res. Bull.
2994	Stability Measurements of $\text{CO}_2\text{-N}_2\text{-He}$ Lasers at $10.6 \mu\text{m}$ Wavelength	C. Freed	Accepted by IEEE J. Quant. Electron.
2998	Hall Coefficient and Transverse Magnetoresistance in HgTe at 4.2°K and 77°K	T. C. Harman J. M. Honig P. Trent	Accepted by J. Phys. Chem. Solids
3018	Growth of Single Ti_2O_3 Crystals from the Melt	T. B. Reed R. E. Fahey J. M. Honig	Accepted by Materials Res. Bull.
3023	Laser Emission from Electron Beam Excited ZnTe	C. E. Hurwitz	Accepted by IEEE J. Quant. Electron.

Meeting Speeches[†]

MS No.

1629B	Spontaneous Band Ferromagnetism in Metallic Oxides	J. B. Goodenough	Materials Research Unit Seminar, McMaster University, Ontario, Canada, 20 March 1967
1629C	Relation Between Structural and Magnetic Properties of Transition-Metal Compounds	J. B. Goodenough	Solid State Chemistry Conference, Brown University, 3 – 5 April 1967
1836	Effect of High Pressures on the Structures and Properties of Some Solids	M. D. Banus	
1719E	Interstellar OH Maser Emission	A. L. McWhorter	Seminar, University of Colorado, 17 March 1967
1787B	Spin Waves in Paramagnetic Fermi Gases	L. L. Van Zandt	Seminar, Wayne State University, Detroit, Michigan, 16 February 1967
1793A	Polaron Self-Energy Effects in InSb	E. J. Johnson	Seminar, Purdue University, 7 March 1967
1830B	Metallic Properties of Certain Metal Oxides	J. M. Honig	Colloquium, Brandeis University, 7 March 1967

* Author not at Lincoln Laboratory.

† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

MS No.

1846A, B	An Effective Hamiltonian for the Optical Properties of Si and Ge	G. F. Dresselhaus	Seminar, New York University, 24 February 1967; Colloquium, University of Illinois, 17 March 1967
1848	Kinetics of Electron Transfer Between Conduction Band and Sulfur Donors in GaSb	G. W. Iseler A. J. Strauss	
1860	Fourier Expansion of the Phonon Dispersion Relations for Silicon and Germanium	G. F. Dresselhaus	
1861	Magneto-optical Evidence for the Existence of a Complex Band Edge at the Energy Gap of the Layer Compound GaSe	J. Halpern J. L. Brebner* E. Mooser*	
1866	Current Modulated Reflectance of Nickel from 0.1 to 10 eV	W. J. Scouler J. Feinleib J. Hanus	
1867	Observation of Exciton Fine Structure in the Interband Magneto-Absorption of InSb	E. J. Johnson	
1868	Magnetoolectroreflectance at 1.5°K	C. R. Pidgeon* J. Feinleib S. H. Groves R. J. Phelan, Jr.	American Physical Society, Chicago, 27 - 30 March 1967
1869	NMR in the Ferromagnetic Semiconductor CdCr ₂ Se ₄	M. Rubinstein* G. H. Stauss* J. Feinleib A. Wold*	
1873	Critical Behavior of the Zero-Field Susceptibility for Heisenberg Models	H. E. Stanley	
1874	Negative Magnetoresistance Effects in Ti ₂ O ₃	J. M. Honig L. L. Van Zandt J. B. Sohn T. B. Reed	
1875	Symmetry of the Ground Level of a Hamiltonian	W. H. Kleiner T. A. Kaplan	
1876	High Efficiency Infrared Photo-voltaic Effect in Metal-Oxide-Semiconductor Structures	R. J. Phelan, Jr. J. O. Dimmock	

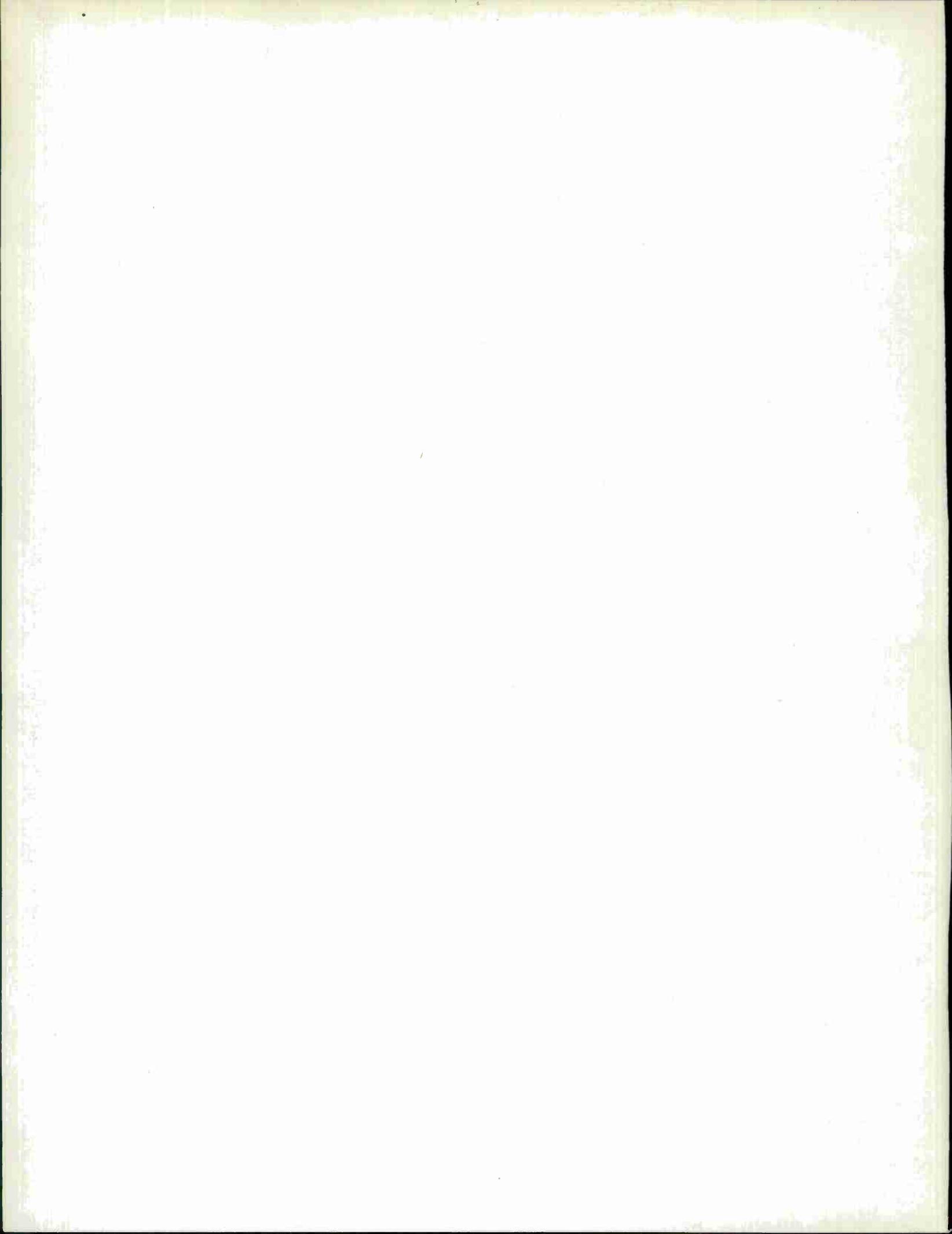
* Author not at Lincoln Laboratory.

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MS No.			
1877	Observations on the Existence of a Phase Transition in Two-Dimensional Heisenberg Models	T. A. Kaplan H. E. Stanley	
1878	Landau Damping of Magnetoplasma Waves for General Closed Fermi Surfaces	A. L. McWhorter J. N. Walpole*	
1880	Laser Action and Photovoltaic Effect in $Pb_{1-y}Sn_ySe$ Diodes	J. F. Butler A. R. Calawa I. Melngailis T. C. Harman J. O. Dimmock	
1882	Raman Scattering from Plasmons and Phonons	A. Mooradian	American Physical Society, Chicago, 27 - 30 March 1967
1891B	Inversion of Conduction and Valence Bands in $Pb_{1-x}Sn_xSe$ Alloys	A. J. Strauss	
1924	Microwave Magnetoacoustic Effects in Indium Antimonide	K. W. Nill	
1931	Optical Modulation in Semiconductors and Metals	J. Feinleib	
1850	Recent Developments in Mass Spectroscopy	E. B. Owens	Society of Applied Spectroscopy, Newton, Massachusetts, 10 January 1967
1882B	Raman Scattering in Semiconductors	A. Mooradian	Seminar, Purdue University, 7 April 1967
1882C	Raman Scattering from Plasmons and Phonons	G. B. Wright	Seminar, M. I. T., 11 April 1967
1891	Physical Properties and Band Structure of $Pb_{1-x}Sn_xSe$ Alloys	A. J. Strauss	Colloquium, Naval Ordnance Laboratory, Silver Spring, Maryland, 21 February 1967
1899	Properties of $Pb_{1-x}Sn_xTe$ and $Pb_{1-x}Sn_xSe$ Infrared Detectors	I. Melngailis	
1907	Physical Properties and Band Structure of $Pb_{1-x}Sn_xTe$ and $Pb_{1-x}Sn_xSe$ Alloys	A. J. Strauss T. C. Harman	IRIS Infrared Detector Specialty Group, Wright-Patterson Air Force Base, 6 - 7 March 1967
1908	Infrared Heterodyne Detection of CO_2 Laser Radiation in Ge:Cu and in $Pb_xSn_{1-x}Te$	M. C. Teich	

* Author not at Lincoln Laboratory.

MS No.			
1903	Light-by-Light Scattering and Pulse Self-Strengthening	P. L. Kelley	Seminar, Ford Motor Scientific Research Laboratory, Dearborn, Michigan, 13 February 1967
1904	High-Temperature Expansion of the Spin Correlation Function for Heisenberg Models	H. E. Stanley	Seminar, Bell Telephone Laboratories, Murray Hill, New Jersey, 16 February 1967
1915	The Heisenberg Model of Magnetism	H. E. Stanley	Colloquium, Temple University, 6 March 1967
1919	Band Structure and Applications of $Pb_{1-x}Sn_xTe$ and $Pb_{1-y}Sn_ySe$	I. Melngailis	Seminar, Colorado State University, 2 March 1967
1931B,C	Optical Modulation in Semiconductors and Metals	J. Feinleib	Seminar, Harvard University, 26 April 1967; Seminar, Ford Motor Scientific Research Laboratories, Dearborn, Michigan, 8 May 1967
1952A	Observation of Magneto-Elastic Coupling by Spin Wave Resonance	R. Weber	Seminar, Case Institute, Cleveland, Ohio, 9 May 1967
1964	On High-Temperature Expansions for the Heisenberg Model	H. E. Stanley	17th Statistical Mechanics Meeting, Yeshiva University, New York, 6 April 1967
1968	Negative Magnetoresistance Effects in Ti_2O_3	L. L. Van Zandt	Seminar, Purdue University, 25 April 1967
1975	A Carbon Dioxide Laser Radar System	H. A. Bostick	3rd DoD Conference on Laser Technology, Pensacola, Florida, 18 - 20 April 1967
1977	Polarons in Indium Antimonide	D. M. Larsen	Seminar, Naval Research Laboratory, Washington, D. C., 21 April 1967
2001	Dynamics of Intense Light Beams in Nonlinear Media	P. L. Kelley	Colloquium, Pennsylvania State University, 9 May 1967



SOLID STATE DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Single crystals of $\text{Pb}_{1-y}\text{Sn}_y\text{Se}$ have been grown by the Bridgman technique with compositions up to $y = 0.3$. The as-grown material exhibits a very high degree of Pb-Sn ratio homogeneity but is consistently heavily p-type with high carrier densities. Carrier concentrations and 77°K Hall mobilities of $9 \times 10^{16} \text{ cm}^{-3}$ and $25,000 \text{ cm}^2/\text{V sec}$ in p-type material, and of $1.5 \times 10^{17} \text{ cm}^{-3}$ and $42,000 \text{ cm}^2/\text{V sec}$ in n-type material, have been obtained by annealing the material in a two-zone furnace.

The interdiffusion parameters of Pb and Se in PbSe have been studied by introducing controlled deviations from the stoichiometric concentration. Excess Se was diffused into Pb-rich n-type material, and excess Pb was diffused into Se-rich p-type material, forming in each case a p-n junction. The diffusion constants were obtained by plotting the junction depth as a function of time.

$\text{Pb}_{1-y}\text{Sn}_y\text{Se}$ lasers and photovoltaic detectors have been fabricated over a wide composition range. Laser emission has now been observed out to 18.9μ and photovoltaic response to 22μ at 12°K. Close agreement is observed between the emission wavelength and the cutoff wavelength of the photovoltaic response in lasers and detectors fabricated from the same material. Results show that the energy gap of $\text{Pb}_{1-y}\text{Sn}_y\text{Se}$ varies with Sn content in much the same manner as that of $\text{Pb}_{1-x}\text{Sn}_x\text{Te}$.

Efficient photovoltaic detectors of infrared radiation at wavelengths up to 11μ which operate at 77°K have been fabricated from annealed Bridgman-grown $\text{Pb}_{1-y}\text{Sn}_y\text{Se}$ single crystals. Responsivities of 3 V/W at 77°K, and internal quantum efficiencies of about 20 percent, have been obtained. The detector noise is less than the noise of the measuring system yielding an upper noise limit of 10^{-10} V sec . This corresponds to a minimum D^* of $3 \times 10^9 \text{ cm/W sec}^{1/2}$ near the peak at 11μ . The detector risetime at 77°K is 20 nsec, which can be accounted for by the RC time constant of the device.

A method has been proposed by which infrared radiation is efficiently converted directly to visible radiation by a single solid state device. The device consists of a capacitor-photodetector-photoemitter sandwich in which infrared radiation is incident on one face and the visible radiation is emitted from the opposite face. The low-level current produced by the infrared detector is integrated and stored by the capacitor and then delivered to the light emitter in short high-current pulses. The feasibility of such a pulsed device has been demonstrated using an indium-antimonide diode detector and a gallium-arsenide-phosphide diode emitter to convert infrared radiation of wavelengths up to 5.3μ into visible radiation between 0.6 and 0.7μ with a quantum efficiency of 10^{-4} .

Electroluminescence has been observed at 4.2° and 77°K from CdS vapor-grown single-crystal platelets with indium contacts bonded to opposite faces of the 10- to $20-\mu$ thick samples. Current densities as high as $2 \times 10^4 \text{ A cm}^{-2}$ under pulsed conditions and 100 A cm^{-2} DC have been

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obtained. At low temperatures, luminescence appears at about 10 A cm^{-2} DC with light intensity increasing rapidly with current. External quantum efficiencies between 10^{-6} and 10^{-5} were obtained at 10^3 A cm^{-2} .

We have obtained laser emission from ZnTe excited by an electron beam with up to 90 W of peak output power at 5280 \AA and 8-percent overall power efficiency at liquid helium temperature, and up to 25 W at 5310 \AA and 2-percent overall power efficiency at 77°K . The lowest threshold observed was 48 keV, which is high compared with the other II-VI compounds.

II. OPTICAL TECHNIQUES AND DEVICES

A CW Doppler radar has been constructed using a 5-W CO_2 laser and a helium-cooled Cu-doped Ge heterodyne detector. Moving vehicles have been detected out to ranges of 2 miles.

A sealed-off 5-W CO_2 laser tube has been operated for more than 700 hours by reclaiming the CO_2 gas from the cathode region. The CO_2 adsorption at the nickel cathode was reversible, and this gas was again replaced in the tube fill by heating the cathode region to 300°C .

Narrow-band operation of a $\text{Pb}_{1-x}\text{Sn}_x\text{Se}$ photovoltaic detector at 77°K has yielded heterodyne detection sensitivities close to the theoretical limit.

Faraday rotation in indium antimonide is being used to construct an isolator at $10.6\text{-}\mu\text{m}$ wavelength.

III. MATERIALS RESEARCH

Single crystals of MnBr_2 have been grown from the melt and from the vapor phase by a method in which helium was used as a carrier gas to transport MnBr_2 vapor produced by the reaction between Br_2 vapor and Mn powder at 850°C . A large-grained ingot of EuO was prepared in a sealed molybdenum crucible by solidification of a non-stoichiometric melt heated to 2000°C and slowly cooled.

Isothermal measurements of resistivity as a function of time for S-doped GaSb have shown that the transfer of electrons from the conduction band to the sulfur donor levels is characterized by two time constants, both of which vary exponentially with reciprocal temperature. The slower constant increases from 5 min. at 90°K to 1300 min. at 77°K , and the faster constant increases from 1.6 to 230 min. over the same temperature range.

Data on the resistivity of Ag_2Te as a function of temperature and hydrostatic pressure have been used to construct a pressure-temperature diagram for this compound. The structure of $\text{Ag}_2\text{Te-III}$, which is the stable phase at room temperature for pressures above 25 kbars, was found to be tetragonal on the basis of x-ray diffraction results obtained with a new high-pressure camera.

The effect of high pressure on the properties of titanium monoxide (TiO_x), which has the rocksalt structure, has been studied by annealing samples with x between 0.87 and 1.06 at about 50 kbars and 1100° to 1300°C for 1 to 3 hours. This treatment reduced the concentration of vacancies from 14 - 15 percent to 11 - 13 percent of the total number of lattice sites, and increased the superconducting transition temperature from less than 1.2°K to between 1.3° and 1.8°K .

Measurements with a vibrating coil magnetometer have shown that the Curie temperature of ferromagnetic SrRuO_3 , which is 164°K at atmospheric pressure, decreases linearly with

increasing hydrostatic pressure at the rate of $0.63^{\circ}/\text{kbar}$. This decrease supports the hypothesis that the magnetic properties of this material are primarily due to band effects rather than to localized moments.

An electron density difference map for PbRuO_3 has been obtained by computer calculation from integrated x-ray intensity data. This map confirms the existence of a trap-mediated Pb-Pb bond in PbRuO_3 , as proposed previously on the basis of structure refinement calculations.

An analysis has been made of the factors influencing the Néel temperature in magnetic materials with perovskite and related structures. It was shown that the theoretical expression for the variation of Néel temperature with lattice parameter cannot be adequately tested if the lattice parameter is changed by chemical substitution rather than by applying pressure.

IV. PHYSICS OF SOLIDS

In extending the magneto-electroreflection studies, a mechanically integrated thin film package has been developed. This dry package has eliminated the temperature and wavelength restrictions which have limited the liquid electrolyte technique, thereby making the method competitive with piezoreflectance.

The anomalous exciton peaks previously reported for InSb have not been observed in germanium. This result, taken in conjunction with calculations by Bell and Rogers, suggests that the anomalies arise from the lack of inversion symmetry of InSb.

A magneto-optical investigation is being undertaken to determine energy band changes in the transition from semimetal to semiconductor as bismuth is alloyed with antimony. To date, sharp magnetoreflection oscillations have been observed in the alloy $\text{Bi}_{0.97}\text{Sb}_{0.03}$.

The current modulated reflectance data of gold has been analyzed. Qualitative agreement with the observed structure was obtained.

Recent experimental investigations of the magnetic energy levels of donor impurities in InSb have prompted a variational calculation of the impurity ground state and the lowest lying $M = \pm 1$ excited states. Comparison of the results with experiment suggests tentatively a central cell correction which increases with magnetic field.

Work on the phonon dispersion relations for silicon and germanium is continuing. By incorporating the shell model within the Fourier expansion technique, a more rapid convergence of the series is obtained; for silicon, calculations using up to and including fourth-nearest-neighbor terms for the ion cores, and the lowest nonvanishing terms for the core shell interaction, give reasonable agreement with the experimental neutron diffraction data.

In order to explain the transport anomalies in Ti_2O_3 , a two-band model has been proposed. By allowing the energy band structure to change continuously in the temperature region of sharp resistivity change (540°K), a resistivity is calculated which agrees with the experiments in all important respects, unlike the magnetic phase transition theory which is inconsistent with the magnetoresistance data.

The Landau transport equation of a Fermi liquid in the presence of dilute random impurities has been attacked by the temperature technique of Luttinger and Ward. Although the calculation has been carried out only in the limit of zero temperature, it is felt that the first temperature corrections may be obtained from this method.

Division 8

In the continuing study of distant-neighbor magnetic interactions in spinels with nonmagnetic A-sites, preliminary neutron diffraction measurements in $ZnCr_2S_4$ indicate a rather complicated spiral pattern at very low temperatures. A thorough study of the magnetic behavior of this material is planned in collaboration with Brookhaven National Laboratory.

Antiferromagnetic resonance in the frequency range 35 to 70 GHz has been observed in single crystals of MnI_2 at liquid helium temperatures where the Mn^{2+} spins order in a flat spiral configuration. In addition to the main resonance, several weaker ones were observed; a theoretical analysis is being attempted.

High temperature expansions of the internal energy, entropy, and specific heat for the classical Heisenberg model have been carried out. The first ten coefficients have been numerically evaluated for various two- and three-dimensional lattices. This expansion technique has also been used to obtain expressions for the zero-field reduced susceptibilities of the Ising and Heisenberg models and to show the similarity between them.

Electronic Raman scattering has now been obtained from phosphorous donors and boron acceptors in silicon. Phonon Raman scattering involving the creation of one virtual zone-center optical phonon with subsequent decay through the anharmonic interaction into two acoustic phonons has also been observed.

The ultraviolet-pumping model for interstellar 18-cm OH emission and anomalous absorption has been extended to include effects of thermal electron collisions, overlapping pump absorption lines, and selective far infrared absorption. Analyses have been made of the possibility of maser action in SH₂, of unusual gain frequency profiles, and of stability of pure circularly polarized emission.

Investigation is continuing of the mode structure in a resonant Raman oscillator consisting of a quartz sample cavity with plane, parallel end faces. The spacing of the modes, which is consistently 20 percent closer than expected from the cavity lengths, is likely to be caused by quartz resonator mode pulling.

A technique has been developed for producing high-power pulses of coherent light with frequency continuously tunable over a 1000-Å range. Although so far the method has been used to generate visible light, in principle it is applicable for a tunable far infrared source.

High-power mode locked output has been obtained in a rotating prism Q-switched ruby laser without the use of separate cavity modulators. The number of modes involved is small and the deduced peak power is 50 MW.

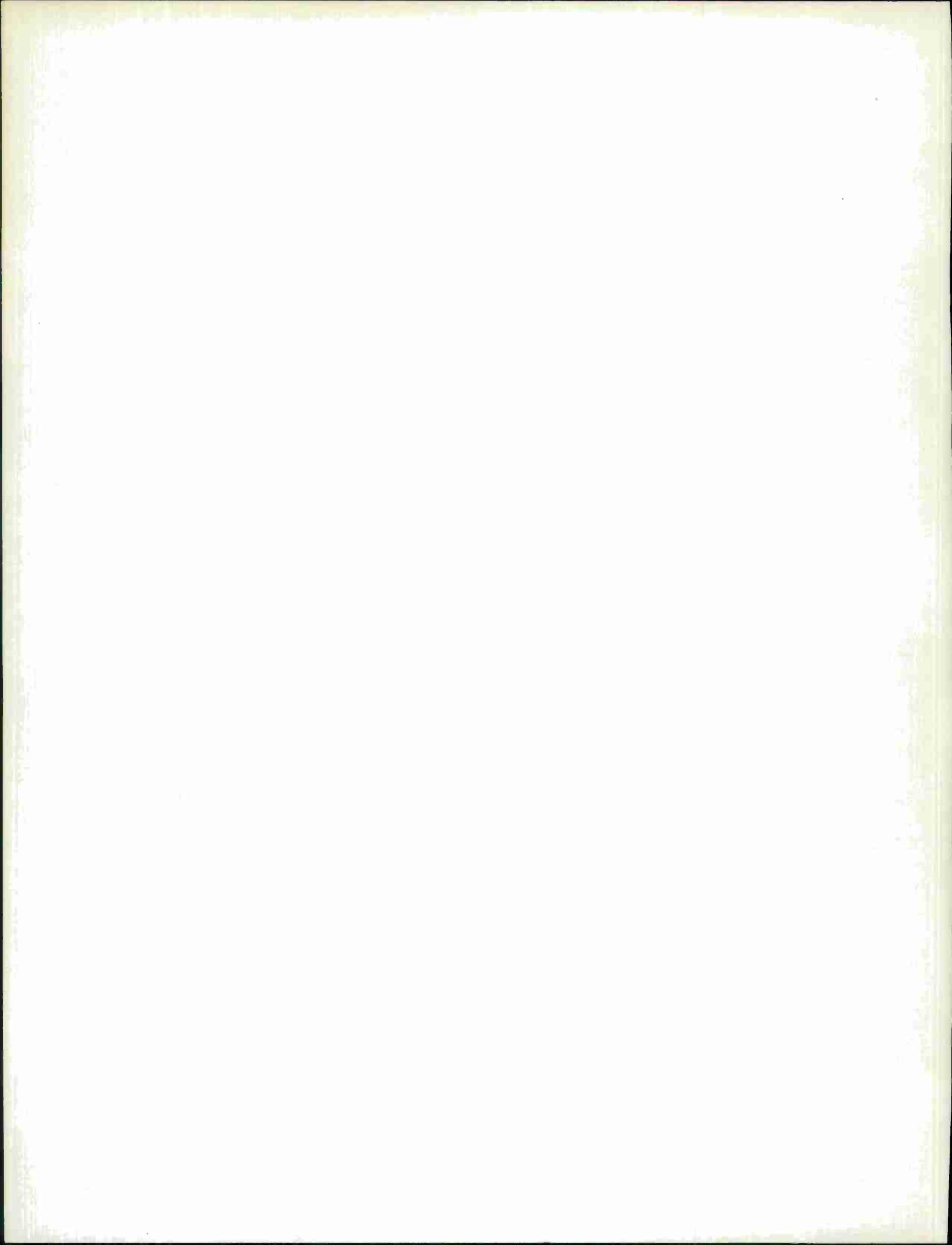
A cyanide laser, which operates at 337μ , has been constructed. It will be used for far infrared spectroscopic investigations.

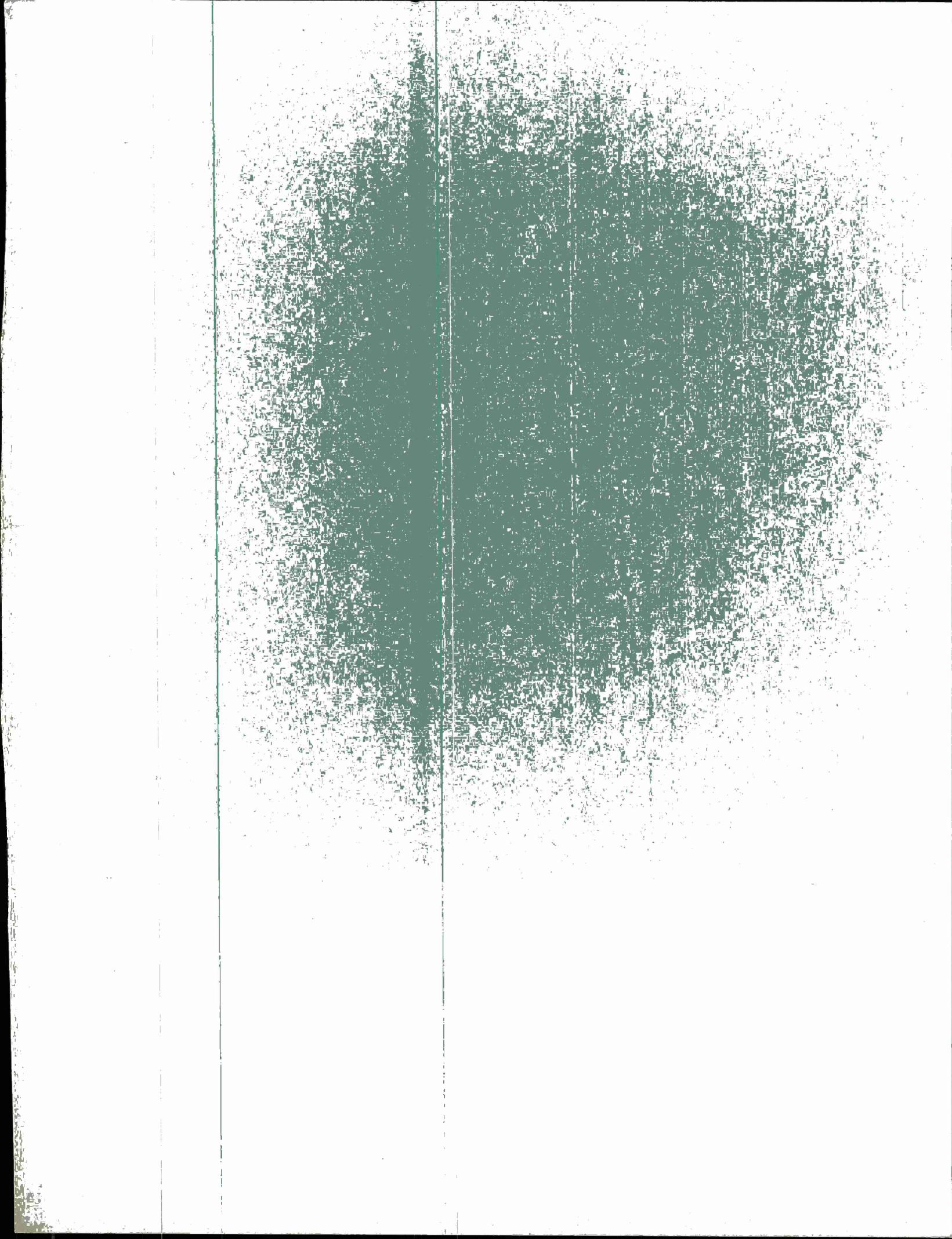
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